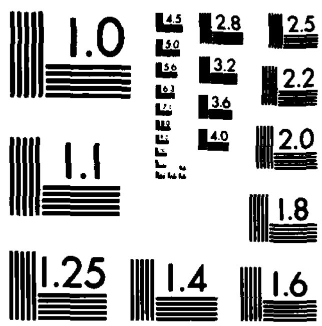
AD-A099 777 SURVEY AND ASSESSMENT OF MODELS OR DECISION RULES DETERMINING SPARE PARTS..(U) AUTOMATION INDUSTRIES INC SILVER SPRING MD VITRO LABS DIV R I POWELL ET AL. 1/10

UNCLASSIFIED 07 SEP 79 TR-03133.100-1-APP-A F/G 15/5 NL



MICROCOPY RESOLUTION TEST CHART
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AD/A099 777

ADA-099777

SURVEY AND ASSESSMENT OF MODELS OR DECISION RULES DETERMINING SPARE PART LEVELS FOR NAVY ELECTRONICS EQUIPMENTS, APPENDIX A, APPLICABLE LITERATURE SOURCE MATERIAL

R. I. Powell, et al

Automation Industries, Inc.
Silver Spring, MD

SEP 79

1346

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER
TR 03133 100-1

2. GOVT ACCESSION NO.
AD-A099777

3. RECIPIENT'S CATALOG NUMBER

4. TITLE (and Subtitle)
SURVEY AND ASSESSMENT OF MODELS OR DECISION RULES DETERMINING SPARE PART LEVELS FOR NAVY ELECTRONICS EQUIPMENTS; APPENDIX A APPLICABLE LITERATURE SURVEY MATERIAL

5. TYPE OF REPORT & PERIOD COVERED
TECH REPORT

6. PERFORMING ORG. REPORT NUMBER

7. AUTHOR(s)
MR Robert Ingram Powell, EE
MR Richard A Lutz, EE

8. CONTRACT OR GRANT NUMBER(s)
N00039-79-C-0187

9. PERFORMING ORGANIZATION NAME AND ADDRESS
AUTOMATION INDUSTRIES, INC.
VITRO LABORATORIES DIVISION
14000 GA. AVE SILVER SPRING, MARYLAND 20910

10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS

11. CONTROLLING OFFICE NAME AND ADDRESS
CODE 8131
NAVAL ELECTRONICS SYSTEMS COMMAND
WASHINGTON, DC 20360

12. REPORT DATE
7 SEPTEMBER 1979

13. NUMBER OF PAGES
900

14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)

15. SECURITY CLASS. (of this report)
Unclassified

15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)
Distribution unlimited. Approved for public release.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)
SPARES PROVISIONING

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE
S/N 0102-LF-014-6601

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

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ADA-099 777

10 Robert Imran Powell

Technical Report Number TR-03133.100-1

SURVEY AND ASSESSMENT OF MODELS OR DECISION RULES DETERMINING SPARE PART LEVELS FOR NAVY ELECTRONICS EQUIPMENTS

APPENDIX A
APPLICABLE LITERATURE SOURCE MATERIAL

7 September 1979

AUTOMATION INDUSTRIES, INC.
VITRO LABORATORIES DIVISION
14000 GEORGIA AVE.
SILVER SPRING MARYLAND 20910
(301) 871-7200

Applicable Literature Source List

Title No.	Literature Source	Author
7	Provisioning for Electronics Equipments/Systems	R. Powell and R. Lutz
8	Initial Provisioning with Spare Deterioration	Paul J. Schweitzer
9	FMSO Load List Model	
10	FBM Load List Prediction Model (for Tender)	
11	Stock Provisioning Procedure for the AN/SPS-40 Radar	Arthur Rupp
13	Technique for Determining the Number of Spares with a Prechosen Probability Level	N. E. Lynch and R. S. Morris
14	A Methodology for Estimating Expected Usage of Repair Parts with Application to Parts with no History	S. E. Haber and R. Sitgreaves
15	The Allowance Parts List	
18	Reliability Approach to the Spare Parts Problem	C. H. Ebel and A. J. Lang
20	On Optimal Redundancy	Guy Black and Frank Proschan
26	Spare Parts Kit at Minimum Cost	Guy Black and Frank Proschan
30	Spares and System Availability	J. Vanden Bosch
31	A Monte Carlo Approach to Spare Provisioning	R. S. Sebeny
32	An Optimal Allowance List Model	Mina Gooray
36-37-38	POLARIS Logistics Studies 1, 2, 3	M. Denicoff, J. Fennell, S. Haber, W. Marlow, F. Segel, H. Solomen
40	OPNAV Instruction 4441.12A, Supply Support of the Operating Forces	
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7)

MR. ROBERT INGRAM POWELL, E.E.

and MR. RICHARD A. LUTZ, E.E.

OPTIMUM SPARES PROVISIONING METHOD FOR ELECTRONIC EQUIPMENT/SYSTEMS

THE AUTHORS

Robert Ingram (RIP) Powell, Electronic Engineer, served with the U.S. Naval Intelligence Organization (OP-20) during WWII, and subsequently with the U.S. Army Security Agency (Pacific) during the Korean Police Action. Returning to civilian engineering in 1952, Chief Engineer UHF Systems Engineering, 5th AACS I&M Squadron. With the Pacific Ground Electronic Engineering and Installations (GEEIA); Chief Procurement Engineering Division, Chief Air Ground Communications; with the Naval Ship Engineering Center, Great Lakes, Illinois Division: Head Communications, Head Electronic Countermeasures, Plans and Programs Officer, Acting Technical Director. With the Naval Ship Systems Command in Washington: Head ILS Test Equipment, Tools and Special Equipment. Presently with the Naval Ship Engineering Center, Prince Georges Plaza, Hyattsville, Md. Head Secondary Support.

Mr. Richard A. Lutz has seven years of engineering experience of which the past year has been specifically in Reliability Engineering and Logistic Support Engineering. He was employed by the Collins Radio Company as an Equipment Design Engineer for UHF/VHF communication transmitters and receivers. He was assigned as Project Engineer for the UHF/FM transmitter for the Apollo Spacecraft and for solid state transmitter sections of military communication equipment in 1963. In August 1967, he was appointed Branch Head of the 3M, CASREPT, and Reliability Branch at the Naval Ship Engineering Center, Great Lakes Division. He holds a B.S. degree from the University of Illinois and has attended graduate courses at the State University of Iowa and the Iowa State University.

PROVISIONING IS THE process of determining the range and depth (quantity) of items of repair parts, i.e: *resistors*, *transformers*, *capacitors*, *modules*, *assemblies*, etc., required to support and maintain an end item, equipment or material for an initial period of service. The period of service generally described as the *mission time* during which the equipment must survive with spare parts furnished, without resupply.

To facilitate understanding the immensity and complexity of the World's largest hardware acquisition, consider an Aircraft Carrier of the U.S.S. Enterprise Class with a range of 883 different electronic equipments. Adding redundancy (Backup) in equipments to establish depth, over 17,000 total electronic equipments carried aboard, with equipment repair part range in discrete parts exceeding 17,000 items and a total depth of more than 93,000 repair parts, representing a dollar value for initial support of approximately $1,134,000 dollars for one ship. The dollar figure represents the On-Board Repair Parts Support (OBRP) for a *90 day period, and does not consider parts procured for systems stock ashore, Fleet issue ships, Repair Depots, Civilian Contractors and parts replaced every 90 days thereafter. Allowance Parts Lists (APL's) are supply/technical aids which have indicated the range and depth of repair parts (OBRP) to be carried on-board the ship, and additional information concerning the part. Determinate on complexity, equipment may have from 1 to over 150 APL's describing part/allowances for the equipment system configuration. During the provisioning process, equipment, maintenance and provisioning engineers, together with fleet equipment oriented technicians make up to 24 decisions per part, preparatory to processing the APL through the current NAVSUP model that considers the APL's for all equipments on the ship and eventually "Prints out" Consolidated On-Board Ships Allowance List (COSAL).

This paper addresses a scientific method applicable across DOD and Industry for deployed electronic equipments, systems, subsystems and functional elements thereof, specifically for the purpose of this paper for the U.S. NAVY. The methodology maximizes effectiveness for a given budget, or establishes the budget for a stated effectiveness, i.e: allows for the 1st time, defense of the budget to provide a predetermined stated effectiveness and the negative affect on effectiveness caused by arbitrary budget cuts.

The current Navy Provisioning Methodology has the following weaknesses:

(a) It does not definitely evaluate the effectiveness of support provided.

(b) It is not cost effective in comparison with the model presented, and

(c) it does not have optimization capability to provide justification and defense of budget requirements, nor therefore allow a definite evaluation of the impact of arbitrary budget reductions.

Spare Parts Provisioning for the U. S. Navy must proceed from a model capable of satisfying two separate requirements for maintenance parts.

(a) A maintenance part kit satisfactory to provide support at each equipment site for a specified time period (an Allowance Parts List (APL) and/or Coordinated Shipboard Allowance List (COSAL) and;

(b) A back-up set of maintenance spare parts satisfactory to provide the requirements of all equipment installations with said parts not stocked in the on-site kit, and to refurbish the on-site kits when parts are used from said kits. The back-up set of maintenance parts must "normally" satisfy the requirements of the system for a much longer time period than the individual on-site kits.

In a dollar oriented world, the ideal system must provide a budget oriented and justifying cost effective system capable of providing a definite confidence that a "stock out" would not occur during a specified mission duration. Such a system would provide:

(a) Optimum system support vs cost.

(b) The best mix of parts i.e: maximum support when funding for optimum support was not available.

(c) Tie of the budget to effectiveness of support, and allow for command "trade offs" in response to budget reductions.

Models in use today allow multiple or single constraint optimization processes. A single constraint process might maximize the probability of system spares adequacy with respect to either a cost, weight or volume constraint. A multiple constraint optimization process considering two or more constraints requires the use of the Nations largest computers with maximum memory, maximum storage capacity and long running time. Multiple constraint capability is valuable in optimizing for small boats, submarines and aircraft—however, for the purpose of projecting the most cost-effective system, for general Navy use, we will confine our presentation to a specific type of single constraint process with cost, as one might expect, as the single constraint. Specifically, for an on-site allowance list, we will show that either some high probability of system spares adequacy may be assured while *minimizing* the cost of that assurance, or that the probability of system spares adequately may be *maximized* subject to a fixed system spares cost. Stating our case in either fashion assures the customer's obtaining *maximum protection* value received for dollars spent on spare items, which is our goal.

The paper will specifically illustrate, by use of

*Parts are carried in such depth to provide replacements for parts expected to fail once, or more than once in a 90 day period.

a modified Black and Prochan Method, how an optimum cost on-site allowance list for maintenance parts [1] may be generated for a typical equipment. Allowance lists generated by current methods will be compared with this optimum cost allowance list to determine the effectiveness of each method, through the use of the Navy's Maintenance and Material Management Data System [2] as a common data base. Based on the reported parts usage data for the selected equipment(s) it will also be shown that the modified Black and Prochan Method would have afforded maximum protection for the system at substantial savings in the kit cost.

The use of the model for scientifically forecasting on-board repair parts during the hardware design phase of Integrated Logistics Support (ILS) Life-Cycle Costing will also be discussed.

The results to date, of our continuing look at the state of the art electronics provisioning and computer technology, utilizing the Univac 494's at the Electronic Supply Office, Great Lakes, Illinois- has been so promising, with such apparent reductions in support costs, that we unequivocally recommend the allocation of DOD resources allocations to significantly speed up the evaluation and implementation of this methodology for provisioning of electronic equipments, systems, subsystems and functional parts thereof.

Background

To facilitate development of a scientific approach for the determination of on-board repair parts and in-country support for International Logistics requirements, the Naval Ship Engineering Center, then in Washington, D.C., tasked the Naval Ship Engineering Center, Great Lakes, Illinois Division to recommend and/or develop methodology and specification to satisfy said requirements. An extensive search and evaluation process was conducted over a two year period to determine "what" methodologies were representative of the state of the art, and particularly to evaluate their sensitivity to the Navy Spare Parts Provisioning Process.

Amongst those organizations visited/contacted by the authors were:

- Naval Applied Science Lab, Brooklyn, New York
- Naval Ship Engineering Center, Norfolk Virginia, Washington, Pt. Hueneue
- Naval Supply Systems Command, Washington, D.C.
- U. S. Army, Huntsville, Alabama
- Raytheon Corporation, Waltham, Massachusetts
- Computer Applications, Inc., New York, New York
- Boeing Corporation, Seattle, Washington
- NASA, Huntsville, Alabama
- IEEE. Headquarters, New York, New York
- McMillan and Company, New York, New York
- Goddard Space Flight Center, Maryland
- Rome Air Force Development Center, New York
- Naval Post Graduate School, Monterey, California
- Naval Ship Systems Command, Washington, D.C.
- Naval Material Command, Washington, D.C.
- Defense Documentation Center, Alexandria, Virginia

The Navy 3-M Data Reporting System requires technician annotation of data cards regarding part/assembly/module/tube failures, and related maintenance information. The equipment oriented data is subsequently sent to the Navy Maintenance Data Collection Center for print-out in customer oriented formats, and are used for problem identification, evaluation, etc. The 3-M Data Base is sufficient to include all major ships of the Navy and its equipments. The failure/replacement of parts as represented by special 3-M reports developed by NAVSEC was used as the base-line for evaluation of the models considered meeting the basic requirements for Navy Provisioning.

Introduction

Integrated Logistics Support (ILS) and Life-Cycle Cost Procurement i,e: (cost of ownership methodologies) are becoming a "way of life" for the military as well as commercial contracts. A very substantial, if not most significant portion of any life-cycle cost for a weapons system, or group of weapons systems deployed—is the cost of maintaining Weapons System equipment in working order over a given projected life cycle usage time. Previous and present military and commercial spares provisioning programs have not been optimized in a meaningful manner, and have not/do not consider the essential ingredients that must be considered to provide optimum support for minimum dollars/investment i.e: (1) Maintenance work force staffing, (2) Design for Maintenance part of module storage, (3) Cost and quantities of test and material handling equipments provided, as well as (4) Mission success which depends upon the quantities of maintenance parts being spared, (5) A quantified Military Essentiality Coding (MEC) to provide the hierarchial relationship of ships mission(s) to system, to equipment, to parts, to other resource allocations in support thereof including personnel. This paper is not an attempt to cure all of these problems in one-shot, but for the moment address the provisioning methodologies generally in use:

1 The Percentage Method——Taking a certain arbitrary percentage of total equipment cost or quantities of parts used within the equipment, and sparing according to such cost or part quantity percentage;

2 The Expected Value Method —— (sometimes called the TABLE METHOD) or (NON CONVENTIONAL ALLOWANCE TABLE). Utilizes the av-

erage failure frequency of each part to determine quantity of replacements.

3 The Committee Method——Organizing a spares provisioning conference and using method 1, but spreading out the responsibility and assigning the percentages on an individual part basis; or:

4 The Part Probability Method——(Fleet Logistics Supply Improvement Program-FLSIP) —— Using tables of the cumulative Poisson and Normalized distributions to determine spares quantities for each part type spared based upon part failure rate data, and the individual probabilities of having adequate spares for each part type.

Although the Part Probability Method (FLSIP) described is far superior to the previous three methods in common usage, it is still insufficient as a technique for sparing in that it is neither responsive to the problem of assuring overall high probability of mission success nor is it responsive to the problem of assuring overall minimum cost, in line with life-cycle cost constraints. The four methods described heretofore have the following weaknesses:

1 They do not evaluate the effectiveness of support provided. (i.e: quantify the affect of budget cuts upon effectiveness nor provide the effectiveness in terms of probability of mission success for dollars invested).

2 They are not cost effective when compared with the Model presented in this paper.

3 They do not provide adequate justification and defense of budget requirements, nor do they allow for a definitive scientific evaluation of the affect of arbitrary budget reductions.

A recent paper [3] on systems effectiveness indicates that up to 80% of the average system downtime for Navy Weapons Systems recently studied is attributable to inadequate or improper spares provisioning. Not having the proper maintenance part needed by the system, of course, also introduces "penalty" costs not normally incurred, to insure the subsequent timely acquisition of such an underspared part.

In broadest terms, all of the possible types of spares provisioning methods may be described in inventory control theory [4,5]. Two types of models are possible: 1. Static (a single spares order for a defined period of time, as on shipboard) and 2. Dynamic (subject to any number of spares recorders). Within the two models types, it is possible to have any one of three conditions: 1. Certainty (knowing precisely when each spare item will be needed), 2 Risk (knowing the probability distribution of demand for spare items), and 3. Uncertainty (not knowing the probability distribution of demand for spare items).

The situation at the equipment site, of course, calls for a static model, under risk, since we are interested in sparing, before mission start, for some specific period of time subject to knowledge of the probability distribution of demand for spare items during the mission.

The approximate demand distribution of a part or module may be determined through part or module replacement data, from which the approximate mean and variance of that distribution may be determined. For purpose of exposition in this paper, and upon observing part or replacement demand distributions in general from the field, it has been assumed that spare item demand time distributions approach exponentiallity (demand for replacement parts occurs at a constant rate, giving rise to the Poisson distribution) . . .

As mentioned briefly in the summary, there are spares provisioning methods which are superior to the four methods just described. These superior methods *have not* seen common use in spares provisioning practice because in many cases it has become difficult for the non-mathematician to appreciate advantages which could have accrued by their use.

This paper specifically addresses one method, A modified Black and Prochan Optimum Spares Provisioning Methodology; which after exhaustive evaluation of the state of the art, is most capable of providing the support and trade-off orientation required in the dynamic dollar oriented world of provisioning. For selected Naval Shipboard Equipment/Systems, we will "bump" the 3-M reported failure/replacement of parts data base against the "prognostication" capabilities of the following models to determine which would have provided the maximum effectiveness for the dollar investment.

The Black and Proschan Method [6]

This method of determining an optimal spares kit subject to a cost constraint is based upon the fact that for each addition of a part to the spares kit there is a marginal increase in assurance of not exhausting the spares. Correspondingly, for each addition of a part to the spares kit there is a marginal increase in cost of the spares kit. Black and Proshcan [6] have shown that for the spare kit to be one of the optimal set of spare kits that

$$r_1 = r_2 = r_3 = r_m = \frac{\Delta R_1}{C_1} = \frac{\Delta R_2}{C_2} = \frac{\Delta R_3}{C_3} = \ldots \frac{\Delta R_m}{C_m}$$

where:

$$r = \frac{\log P_i\,(n_i + 1) - \log P\,(n_i)}{c_i} = \frac{\Delta R_i}{c_i} \quad \ldots\ldots\ldots (1)$$

and:

$$\log P_i\,(n_i + 1) - \mathrm{Log}\, P_i\,(n_i) = \Delta R_i\,(n_i)$$

is the incremental increase in assurance for adding 1 part of type "i" in addition to "n_i" spares, and c_i is the cost of one part of type i.

For the constant failure rate case assumed in [6] and in our introduction

$$r_i \cong \frac{e^{-a_i}\ \ a_i^{(n_i+1)}}{(n_i + 1)!\,c_i} \quad \ldots\ldots\ldots\ldots\ldots (2)$$

were a_i is the usage rate of the 1st part. This given a particularly convenient value to compute, since

$$a_i = \sum_{j=1}^{K} \lambda_j t_j$$

when a part i may be used as many at k times in a system, as the convolution of a Poisson frequency function is a Poisson frequency function.

One example of determining a particular spares kit meeting a probability

$$P(A) = \Pi_{i=1}^{m} P_i (S_i) \ldots\ldots\ldots\ldots (3)$$

where $P(A)$ = the probability or assurance of not incurring system disability due to spares shortage for a given essentiality level.

$P_i(s_i)$ = the probability of assurance of not incurring system disability due to a shortage of spare part type i within given essentiality level.

and where:

$$P_i(s_i) = P\ [N_i(t) < n_i]$$

of not having a spares shortage is shown in Figure 1.

The curve in Figure 1 was arrived at by starting with zero spares of each part type. Then $r_1, r_2, \ldots, r_m$ were calculated for each part type. Then the part type with the largest r_i was added to the spares kit and the overall probability of spares adequacy was recalculated. The kit was calculated one step at a time until either of the following inequalities were met:

$$P_a \leq \Pi_{i=1}^{m} P_i \quad \ldots\ldots\ldots\ldots\ldots\ldots (4)$$

or

$$C_0 \leq \sum_{i=1}^{m} c_i n_i$$

The following is quoted from reference (7), Some advantages of the Black and Proschan Model are:

1. Given the basic parameters—the quantity, failure rate, price and number of operating hours required of each part in the system — the relationship between cost and asurance is readily represented by a plotted curve (see Figure 1) from which the point of diminishing returns may be approximated visually.

2. For a given fixed cost, a spares kit which maximizes logistic readiness can be generated.

3. Conversely, for a given fixed assurance of spares adequacy (Logistic Readiness) as a function of time a spares kit which minimizes cost can be generated.

The situation for the back-up spares at a central location calls for a dynamic model subject to any number of spares reorders under risk, since we are interested in sparing for many equipments, before mission time, subject to the knowledge of a probability distribution of demand for this specified

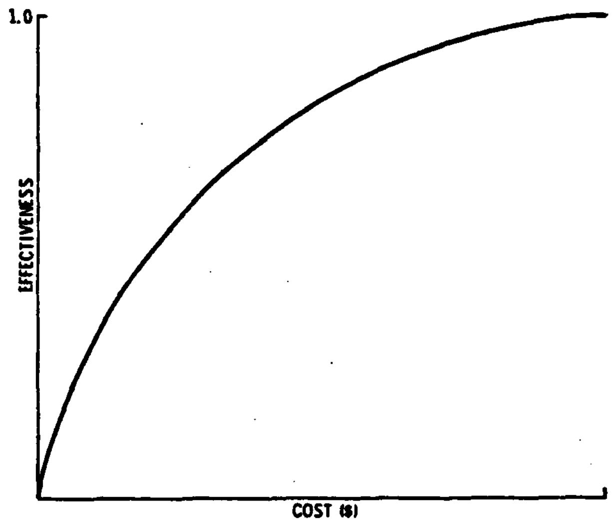

Figure 1.

time. This situation is adequately described in the classical literature on inventory control theory (4), (5) and will not be discussed in further detail in this paper.

Maintenance & Material Management (3-M) System [2]

Implementation of the Maintenance Data Collection Sub-System (MDCS) of the Navy's Maintenance and Material Management System provides the logistician with a useful tool for measuring the effectiveness of an on-site spares list in an actual operation environment. Over ninety per cent of the active fleet is now reporting maintenance and part usage data in the 3-M system. 3-M parts usage data collected over a period of eighteen months to two years for the systems supported by spares lists described previously in this paper was reviewed to establish the effectiveness of the spares lists. For the equipments hereafter identified as "A" and "B", 3-M data from fifty-two ships was used for "A" and sixty-five for "B". Ship type and numbers of ships reporting are as follows:

EQUIPMENT "A"

AGC-3	CGN-1	DE-5
AOE-1	CLG-4	DEG-1
CA-1	CVA-2	DLG-11
CC-1	DD-8	DLGN-1
CG-4	DDG-8	LPH-1

EQUIPMENT "B"

AGC-1	ARC-1	DLG-5
ALA-4	ASR-1	DE-3
AOG-1	CAG-2	DER-3
APA-5	CA-1	LSD-4
APD-1	DD-16	LST-5
AR-1	DDG-2	MSC-3
	DL-2	MSO-4

TABLE 1

EQUIPMENT "A"

Type	*Cost*	*3-M Effectiveness*
Conventional	3,553	.786
FLSIP (90) %	2,130	.495
B-P (90) %	1,860	.748
B-P (95) %	2,432	.855
B-P (99) %	4,100	.945

NOTE: In both cases Modified Black & Prochan Methodology provide increased effectiveness and lower cost.

TABLE 2

EQUIPMENT "B"

Type	*Cost*	*3-M Effectiveness*
Conventional	4,297	.577
FLSIP (90) %	5,926	.360
B-P (90) %	1,552	.606
B-P (95) %	2,890	.675
B-P (99) %	4,739	.758

Observe that in this case "History", i.e.: 3-M reported failure/replacement clearlp evidences that FLSIP cost 3.8 times more than the modiled Black & Prochan Methodology and with little more than half the effectiveness of the B&P Methodology.
For these weapon systems the cost optimized method for determining the spares list would have yielded greater protection for the weapon system at a substantial savings in investment cost.

The reported part usage requirements were matched with the various spares lists to determine the effectiveness of the various lists. The effectiveness of spares were calculated by the following equation:

$$\text{Effectiveness} = \sum_{i=1}^{\infty} \frac{e^{-M}(MA)^{i}}{(i)!} = e^{-S}$$

Where M = Average number of part requirements/ship/90 day mission

S= Average number of part shortages/ship/90 day mission

$$A = (1 - \frac{S}{M})$$

The effectiveness and cost of the various spares lists are measured by the reported usage data are depicted, Tables 1 and 2.

Original Computer Programs were written in Fortran IV to run on the Honeywell 2200 at the Naval Ordnance Station at Forest Park, Illinois, limiting the maximum number of line items under consideration to 900. The Logic Chart is shown in in Figure 2. The running time to provide a spares list at .99 Effectiveness was 15 minutes. Subsequently, in coordination with the Naval Supply Systems Command, Electronic Supply Office, Great Lakes

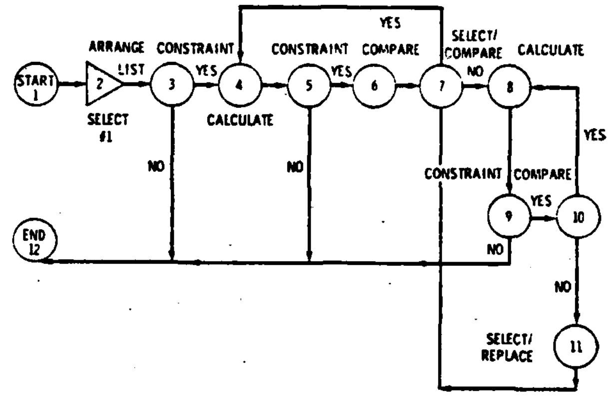

Figure 2. Modified Black and Prochan computer logic chart.

Illinois, the model was programmed to run on the UNIVAC U-494 and presently has the capability to handle 7,000 line items, with a running time of 1.5 hours. Note that 85% of our equipments to be provisioned will be covered by this capability, and to accomodate the largest equipments, the Naval Applied Science Laboratories at Brooklyn, New York estimate that it is possible to handle 30,000 line items on the CDC-6600 with a running time of 3 hours.

We have shown that 3-M data establishes the upper limit of effectiveness when comparing various APL generating methodologies to the same data base. We are working toward computerized 3-M analysis to facilitate development of a quick reaction capability to update APL's and quickly identify and initiate action to solve support problems. We have shown how the modified Black and Prochan Model can be used to:

- Evaluate Effectiveness
- Assure Cost Effectiveness
- Justify and Defend Budget Requirements
- This modified Black & Porchan Math Model/Methodology is far superior to all previous and presently used/known methodologies.

SYSTEMS PROVISIONED

Previously with Modified Black and Prochan Methodologies

AN/SPG-51

AN/BQQ-9

AN/SQS-35

AF 441-L Radar

Nike "X" Radar

TABLE 3

DATA REQUIRED

For Black and Prochan Computer Run	
	Equipment Configuration
	Maintenance Plan
	Part Replacement Rates
	Part Unit Prices

NOTE: The data elements required to run the modified Black & Prochan Math Model as indicated above, would be required and known during the design phase at which time it would be possible to consider the ILS life cycle estimated costs of ownership and make trade-offs before entering the budget cycle. Subsequently the updated data elements would provide the base for intermediate sparing and interim APL's during the period between equipment installation and Naval Supply Systems Command support 2 to 3 years later. Additionally, with subsequent update based on reported 3-M data, NAVSUP in conjunction with NAVSEC, would be able to update the ALLOWANCE PARTS LISTS (APL's), and more scientifically provide follow-on support to the Fleet.

The methodologies utilized to provision the above equipments differ according to constraints, machine techniques, and other factors, e,g: some provisioning lists were started with one each of each item used in the equipment with the math model used to optimize kits in support thereafter. Such a technique starts with the assumption that dollar resources are available, space for storage is available and that the mission of the equipment requires such protection. In real life provisionings, however, we are generally constrained to generate the optimum mix of parts to achieve the greatest degree of protection for a given "remaining" number of dollars available. What we do gain in using the model is the negative affect on probability of mission success and the dollar amount to get the probability to a level satisfactory to CNO, i.e: defense of the budget and the deleterious affect on combat readiness of the fleet, when budgets are cut.

Conclusion:

During the period 1947 to the present, numerous authors (see references) considered the potential benefits of the Black and Prochan Math Model for optimizing spares kits; unfortunately however, the hardware did not exist in those early days to implement the concept in a meaningful cost effective manner.

This paper illustrates how spares lists calculated by various methods can be compared with one another, and measurements of the overall effectiveness and cost of such lists can be calculated through the use of a reporting system such as the Maintenance and Management Data System of the Navy.

Furthermore, for the equipments/systems reported in this paper, we have illustrated that compiling a spares list via the Modified Black and Prochan Model, is an accomplished fact on present day hardware. Moreover, that a spares list calculated in this manner, does in fact provide adequate protection for a weapon system at a substantial savings and higher effectiveness when compared with other methods presently in wide use by Department of Defense.

Additionally; this methodology:

1. Evaluates the effectiveness of support provided,

2. Is cost effective and;

3. Provides adequate justification and defense of budget requirements allowing a definite evaluation of arbitrary budget reductions.

In the World of ILS, with tightening budget constraints, it becomes abundantly clear that we must accelerate the development and implementation of cost effective methodologies which show promise of providing higher effectiveness for fewer dollars, and in this connection the authors recommend that the Navy and other DOD organizations plagued with electronic support problems of the kind addressed in this paper, provide such additional resources as necessary to bring about the progress that can be made possible by the methodology presented.

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Operations Research, v. 15, May 1967

INITIAL PROVISIONING WITH SPARE DETERIORATION

Paul J. Schweitzer

Institute for Defense Analyses, Arlington, Virginia

(Received June 7, 1963)

Initial provisioning is analyzed for the case where parts in use and spares have exponential failure distributions with different failure rates. Expressions are given for system reliability and its asymptotic expansions for small time, large time, large numbers of spares, and small spare failure rate. The incremental reliability associated with each additional spare part is analyzed. Graphs are presented that yield, for arbitrary failure rates of spares and parts in use, the minimum number of spare parts needed to achieve system reliabilities of 90, 95, and 99 per cent.

THE stockpiling of spare parts is a widely used method of achieving high system reliability, and the determination of optimal policies for initial provisioning and reordering is of considerable economic importance.

Spare provisioning is usually carried out either under the assumption that spare parts do not fail or the assumption that spare parts have the same failure rates as parts in use. These assumptions are convenient because the resultant expressions for system reliability, cumulative Poisson or cumulative binomial probabilities, respectively, are easy to work with.

Recently WEISS has shown[1] that even a small amount of spare deterioration results in serious degradation of system reliability. On the other hand, the second assumption may lead to an estimate of system reliability that is considerably too low. — high

Since the two assumptions may lead, respectively, to gross overestimation of system reliability or to gross overprovisioning of spares, their usefulness is open to question. It is apparent that the case of arbitrary spare failure rate needs more detailed investigation. Such a program was begun by Weiss and is continued here for exponentially-distributed lifetimes.

Two results of particular interest are a Maclaurin series expansion of system reliability in powers of the spare failure rate and graphs that yield, for arbitrary failure rates of spares and parts in use, the minimum number of spares necessary for achieving system reliabilities of 90, 95, and 99 per cent. The former leads to conditions for which reliability calculations under the assumption that spares do not fail are approximately valid. Sensitivity analyses performed via the latter can help determine whether obtaining better information about spare failure rates is economically justified.

THE MODEL

WE CONSIDER a system composed of N identical parts with an initial supply of m spares. The N parts in use are assumed to fail independently, each with a constant failure rate λ, while the spare parts are assumed to fail independently, each with a constant failure rate μ.

Failed parts in use are immediately replaced by unfailed spares as long as these are available. Spares that fail or that are put into use are not replaced; hence the spares are gradually depleted. When a part in use fails and no unfailed spares are left, the system is said to fail.

System behavior is indicated schematically in Fig. 1. The state k ($k=0, 1, \cdots, m$) contains exactly k unfailed spares and is one in which the system is operational. Note that state 0 and the state F of system failure are distinct. The transition rate λ_k out of state k is given by $\lambda_k = N\lambda + k\mu$.

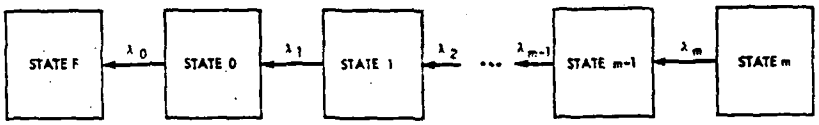


Fig. 1. Schematic diagram of system behavior.

ANALYTIC FORMULATION AND RESULTS

1. Transition Probabilities

The transition probabilities are defined by

$$P_{m,k}(t) = \Pr(\text{system is in state } k \text{ at time } t \mid \text{system is in state } m \text{ at time } 0),$$
$$k=0, 1, \cdots, m, \qquad m=0, 1, 2, \cdots,$$

and describe behavior before the system fails. The equations of motion† for this pure death process are

$$dP_{m,k}/dt = -\lambda_k P_{m,k} + (1-\delta_{m,k})\lambda_{k+1} P_{m,k+1}. \quad (k=0, 1, \cdots, m) \quad (1)$$

They may be solved recursively with the initial conditions $P_{m,k}(t=0) = \delta_{m,k}$ with the result:[1]

$$P_{m,k}(t) = ((N\lambda/\mu)+k+1)_{m-k}[(1-e^{-\mu t})^{m-k}/(m-k)!]e^{-\lambda_k t}, \quad (k=0, 1, \cdots, m) \quad (2)$$

where

† These are a specialization of the Bateman equations of radioactive decay, whose general solution was first given in reference 2.

$$(a)_k=\Gamma(a+k)/\Gamma(a)=\begin{cases}1, & (k=0)\\ a(a+1)\cdots(a+k-1). & (k=1,2,3,\cdots)\end{cases}$$

These transition probabilities also play an important role in the analysis by renewal theory of reorder policies since they describe the system evolution between successive deliveries of spare parts.

2. *System Reliability*

The system reliability $R_m(t)$ is defined by

$$\begin{aligned} R_m(t) &= \Pr(\text{system operational at time } t \mid m \text{ unfailed spares at time } 0)\\ &= \textstyle\sum_{k=0}^{k=m} P_{m,k} \qquad (3a)\\ &= \textstyle\sum_{k=0}^{k=m} ((N\lambda/\mu)+m-k+1)_k[(1-e^{-\mu t})^k/k!](e^{-\mu t})^{(N\lambda/\mu)+m-k}. \qquad (3b)\end{aligned}$$

We note in passing the two special cases

(a) $\mu=0$ (spares do not fail),

$$r_m(t)=R_m(t,\mu=0)=\textstyle\sum_{k=0}^{k=m}[(N\lambda t)^k/k!]e^{-N\lambda t}. \qquad (4)$$

(b) $N\lambda/\mu$ integral,

$$R_m(t)=\sum_{k=0}^{k=m}\binom{(N\lambda/\mu)+m}{k}(1-p)^k p^{N\lambda/\mu+m-k}. \qquad (p=e^{-\mu t}) \quad (5)$$

Case (a) yields cumulative Poisson probabilities for the system reliability while case (b) yields cumulative binomial probabilities. By specialization of case (b) to $\lambda=\mu$, these two cases correspond to the two assumptions discussed in the introduction.

Differentiation of (3a) with respect to t and insertion of (1) leads to the equation of motion

$$dR_m(t)/dt=-N\lambda P_{m,0}(t)=-\mu(N\lambda/\mu)_{m+1}\,[(1-e^{-\mu t})^m/m!]e^{-N\lambda t}. \qquad (6)$$

The probability density $f_m(t)$ of system failure time t, starting with m spares at time 0, is given by

$$f_m(t)=-dR_m(t)/dt=\mu(N\lambda/\mu)_{m+1}[(1-e^{-\mu t})^m/m!]\cdot e^{-N\lambda t}. \qquad (t\geq 0;\ m=0,1,2,\cdots) \quad (7)$$

An alternative derivation of (7) proceeds from the relation

$$t_f=\textstyle\sum_{k=0}^{k=m} t_k, \qquad (8)$$

which expresses the time t_f for system failure, starting with m spares, as the sum of $m+1$ independent random variables. Here t_k is the time for the number of unfailed spares to drop from k to $k-1$ and is exponentially distributed with mean $1/\lambda_k$. It follows from (8) that f_m is the m-fold convolution of the probability densities of the t_k.

The system reliability may alternately be expressed as[1]

$$R_m(t)=\int_t^\infty dy\, f_m(y) \tag{9}$$

$$=I_p\left(\frac{N\lambda}{\mu}, m+1\right), \qquad (p=e^{-\mu t}) \tag{10}$$

where the change of variables $x=e^{-\mu y}$ was made and

$$I_p(c,d)=\frac{\Gamma(c+d)}{\Gamma(c)\Gamma(d)}\int_0^p dy\, y^{c-1}(1-y)^{d-1} \qquad (c,d>0) \tag{11}$$

is the incomplete beta function in PEARSON's notation.[3]

The system reliability is strictly monotone decreasing in t, dropping from $R_m(0)=1$ to $R_m(\infty)=0$. According to (10) and (11), $R_m(t)$ is strictly monotone decreasing in the spare failure rate μ for $m\geqq 1$.

3. Time of System Failure

If the system is started with m unfailed spares at time 0, then the time t_f of system failure has the probability density $f_m(t_f)$ given by (7). The distribution of system failure times is unimodal, the most probable time of system failure being given by

$$t_{\text{mode}}=(1/\mu)\ln[1+(m\mu/N\lambda)]. \qquad (m=0,1,2,\cdots) \tag{12}$$

The mean and variance of the time of system failure are most readily obtained from (8). They are given by[1]

$$E(t_f)=\sum_{k=0}^{k=m} E(t_k)=\sum_{k=0}^{k=m}(1/\lambda_k), \tag{13}$$

and

$$\sigma^2(t_f)=\sum_{k=0}^{k=m}\sigma^2(t_k)=\sum_{k=0}^{k=m}[1/(\lambda_k)^2]. \tag{14}$$

We note with Weiss that the mean and mode of the time to failure grow much slower with m, asymptotically to $(\ln m)/\mu$, if spares fail than if spares do not fail. It is also noteworthy that the mean and mode do not coincide, even when μ approaches zero. This comes as no surprise since the same property holds for the mth order Erlang density to which f_m reduces as μ approaches zero.

According to (13) and (14), the coefficient of variation $\sigma(t_f)/E(t_f)$ is less than unity for $m\geqq 1$, and approaches zero as m grows very large. This is another property which f_m shares with the mth order Erlang density.

4. *Marginal Analysis*

Marginal analysis investigates how much incremental reliability is gained by the addition of each successive spare part. Comparison of (6) with the equation of motion

$$dR_m/dt=-\lambda_m(R_m-R_{m-1}) \qquad (m\geqq 1) \quad (15)$$

leads to the conclusion

$$R_{m+1}-R_m=(N\lambda/\lambda_{m+1})P_{m+1,0}=(N\lambda/\mu)_{m+1} \cdot[(1-e^{-\mu t})^{m+1}/(m+1)!]e^{-N\lambda t}. \quad (m=0,1,2,\cdots) \quad (16)$$

An alternate derivation of (16) is based upon integration by parts of (9). This equation describes the increase in reliability upon addition of the $m+1$st spare.

The ratio g_m of successive increments in reliability is given by

$$g_m\equiv(R_{m+2}-R_{m+1})/(R_{m+1}-R_m)=[(N\lambda/\mu)+m+1] \cdot(1-e^{-\mu t})/(m+2). \quad (17)$$

The right-side of (17) approaches $1-e^{-\mu t}<1$ for large m, so that ultimately each spare adds less reliability than its predecessor. The value m^{**} of m for which $g_m=1$ is given by

$$m^{**}=[(N\lambda/\mu)-1](e^{\mu t}-1)-2.$$

The marginal analysis can be characterized in terms of $[m^{**}]$, the largest integer contained in m^{**}, as follows:

(a) If $[m^{**}]<0$, then each spare from the second on adds less incremental reliability than its predecessor.

(b) If $[m^{**}]\geqq 0$, then each spare from the second to the $[m^{**}]+2$nd adds more incremental reliability than its predecessor. Each spare from the $[m^{**}]+3$rd on adds less incremental reliability than did its predecessor. The ratio of successive increments in reliability decreases monotonically from $g_2\geqq 1$ to $1-e^{-\mu t}<1$.

If spares do not fail, then

$$m^{**}=N\lambda t-2, \qquad (\mu=0)$$

and the last spare that adds more incremental reliability than its predecessor is the $[N\lambda t]$th. This number is essentially the expected number of part failures in a time interval t when the supply of spares is infinite.

The quality R_{m+1}/R_m is monotonically decreasing in m provided m is sufficiently large. This property holds, in particular, for all $m\geqq m^{**}$ since the inequality

$$R_{m+1}/R_m\geqq(R_{m+2}-R_{m+1})/(R_{m+1}-R_m)\equiv g_m$$

is then satisfied. It follows that $\ln R_{m+1}/R_m$ is monotonically decreasing in the region of decreasing marginal reliability. Since this monotonicity is sufficient (reference 4, p. 587) for the validity of the Black-Proschan algorithm for optimal allocation of funds among various subsystems, the algorithm may be applied when spares deteriorate provided each subsystem has received enough spares to be in the region of decreasing marginal reliability.

5. Alternate Expressions for System Reliability

Two additional relations are presented which express R_m as the sum of $m+1$ terms. One is obtained by performing a binomial expansion on (7) and inserting the result into (9):

$$R_m(t)=(N\lambda/\mu)_{m+1}(\mu/m!)\sum_{k=0}^{k=m}\binom{m}{k}(-1)^k(e^{-\lambda_k t}/\lambda_k). \qquad (m=0,1,2,\cdots) \tag{18}$$

The second is obtained by insertion of (16) into

$$R_m(t)=R_0(t)+\sum_{k=1}^{k=m}[R_k(t)-R_{k-1}(t)], \qquad (m=1,2,\cdots) \tag{19}$$

namely,

$$R_m(t)=\sum_{k=0}^{k=m}(N\lambda/\mu)_k[(1-e^{-\mu t})^k/k!]e^{-N\lambda t}. \qquad (m=0,1,2,\cdots) \tag{20}$$

We note that as μ approaches zero, (20) reduces correctly to the cumulative Poisson probability r_m given by (4).

In general, the most convenient analytical expressions for R_m are in terms of the hypergeometric function $F(a,b;c;z)=F(b,a;c;z)$ whose properties are well known.[5, 6] This function is related to the incomplete beta function by [5]

$$I_p(a,b)=[\Gamma(a+b)/\Gamma(a+1)\Gamma(b)]p^aF(1-b,a;a+1;p). \qquad (a,b>0) \tag{21}$$

The usefulness of (21) for manipulative purposes is shown in Appendix A, while its usefulness for asymptotic expansions is demonstrated in Appendix B.

Appendix C tabulates several methods of calculation of system reliability.

6. Mean Number of Part Failures in t

In order to compute the mean $A_m(t)$ and variance $B_m(t)$ of the number of part failures in a time interval t, starting with m unfailed spares, we must

first describe system behavior after the system has failed. The most tractable assumption is that once system failure has occurred, no further part failures can occur. The mean and variance are then given by

$$A_m(t)=\sum_{k=0}^{k=m}(m-k)P_{m,k}(t)+(m+1)[1-R_m(t)],$$
$$B_m(t)=\sum_{k=0}^{k=m}(m-k)^2P_{m,k}(t)+(m+1)^2[1-R_m(t)]-[A_m(t)]^2.$$

Evaluation of these sums is simplified by use of the relation

$$(m-k)P_{m,k}(t)=[(N\lambda/\mu)+m](1-e^{-\mu t})P_{m-1,k}(t). \qquad (m-k\geq 1;\ m=1,2,\cdots)$$

We obtain

$$A_m(t)=[(N\lambda/\mu)+m](1-e^{-\mu t})R_{m-1}(t)+(m+1)[1-R_m(t)], \tag{22}$$

$$B_m(t)=(m+1)^2[1-R_m(t)]-[A_m(t)]^2+[(N\lambda/\mu)+m](1-e^{-\mu t})\cdot\{R_{m-1}(t)+[(N\lambda/\mu)+m-1](1-e^{-\mu t})R_{m-2}(t)\} \tag{23}$$
$$(m=0,1,2,\cdots)$$

using the convention $R_{-1}=R_{-2}=0$.

The mean number of part failures $A_m(t)$ is zero at $t=0$ and approaches $m+1$ for large t. The behavior of $A_m(t)$ for small t is obtained by use of (B.1), with the result

$$A_m(t)=(N\lambda+m\mu)t[1-(\mu t/2)+O(t^2)]. \qquad (m=1,2,3,\cdots;\ N\lambda t\ll 1;\ \mu t\ll 1) \tag{24}$$

The variance $B_m(t)$ of the number of part failures is zero at $t=0$ and approaches zero for large t. We conjecture that it is unimodal. The behavior of $B_m(t)$ for small t is obtained by use of (B.1) with the result

$$B_m(t)=(N\lambda+m\mu)t[1-(3\mu t/2)+O(t^2)]. \qquad (m=1,2,3,\cdots;\ N\lambda t\ll 1;\ \mu t\ll 1) \tag{25}$$

For small t, A_m and B_m are the mean and variance for a pure Poisson process with rate $N\lambda+m\mu$.

AN EXAMPLE

A SYSTEM of $N=2$ identical parts must operate for a period $t=1000$ hours without part replenishment. The failure rates of parts in use and spares are, respectively, $\lambda=10^{-3}$ hour^{-1} and $\mu=0.2\lambda$. How many spare parts should be initially supplied?

We find from (20) that the system reliabilities associated with 3–8 spares are given by $(R_3,\cdots,R_8)=(0.803,\ 0.907,\ 0.960,\ 0.984,\ 0.994,\ 0.998)$. Hence 4 spares are needed for 90 per cent reliability, 5 spares for

95 per cent, and 7 spares for 99 per cent. Since $m^{**} = -0.0074 < 0$, each spare adds less reliability than its predecessor.

If $m=5$ spares are supplied, then the mode, mean, and standard deviation of the time until system failure are given by $[t_{\text{mode}}, E(t_f), \sigma(t_f)] = (2027, 2446, 1008)$ hours. The mean and standard deviation of the number of part failures in $t=1000$ hours are given by $[A_5(1000), \sqrt{B_5(1000)}] = (2.71, 1.46)$. Since $\mu/N\lambda = 0.1 \ll 1$, the system reliability may be calculated from (B.3) as a cumulative Poisson probability with corrections. One obtains

$$R_5(1000) \simeq 0.983436 - 0.018045 - 0.005413 + O(\mu^3) = 0.959978$$

in good agreement with the exact value of 0.960079. We note, in agreement with Weiss, that even this small spare failure rate resulted in noticeable degradation of system reliability and expected system lifetime from their values $(r_5(1000), E(t_f)) = (0.983, 3000$ hours) if spares did not fail.

INITIAL PROVISIONING WITH CONFIDENCE

In order to achieve a reliability A of system performance during a time interval t, at least m^* spares must be supplied, where m^* is the smallest value of m for which

$$R_m(t) \geq A \tag{26}$$

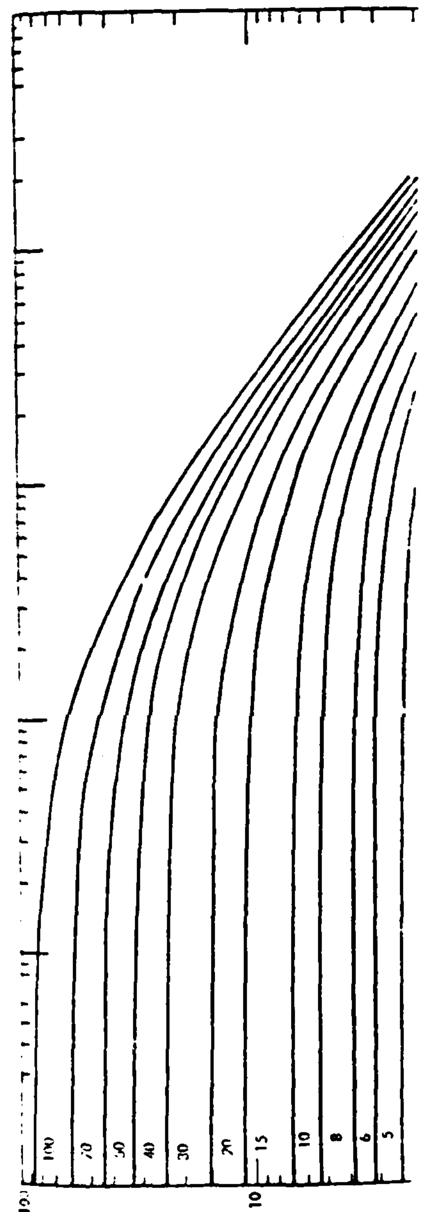
is satisfied.

Equation (10) shows that R_m depends on m and the two dimensionless parameters μt and $N\lambda/\mu$. Consequently, for fixed A, m^* is an integer-valued function of the two-dimensionless variables $\mu/N\lambda$ and $N\lambda t$. It is possible to construct, for each fixed A, a graph whose axes measure these last two variables, and upon which regions corresponding to different values of m^* are marked off.

Such graphs have been constructed for the three cases $A = 0.90$, 0.95, 0.99 (Figs. 2, 3, and 4). The boundaries between regions of different m^* were obtained by digital computer solution of the transcendental equation $R_m(t) = A$ for t, using Newton's method as indicated at the end of Appendix C.

Only the range of values $\mu/N\lambda \leq 2$ has been plotted. This is by far the most important region, since $\mu \leq \lambda$ usually occurs. The boundary for the region $m^* = 0$ does not fall within the regions described by Figs. 3 and 4. It is given by $e^{-N\lambda t} = A$, namely by the horizontal line $N\lambda t = 0.105$, 0.051, 0.010 for the three cases $A = 0.90$, 0.95, 0.99, respectively.

For values of m and A not plotted, m^* may be obtained from (20): successive terms are added to (20) until (26) is satisfied. The special case $N=1$, $\mu=0$ which corresponds to the left edge of our graphs, has been studied and plotted by Barnett.[7]



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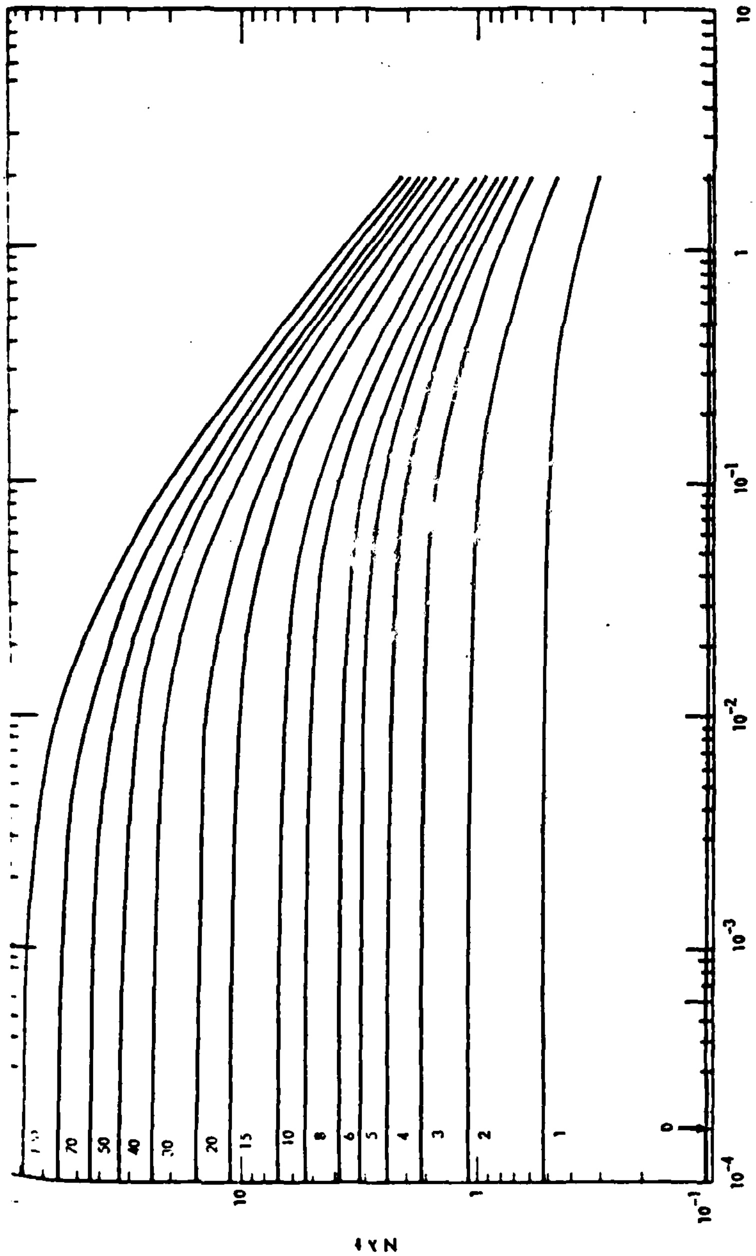


Fig. 2. Spare requirements for initial provisioning with 90 per cent reliability.

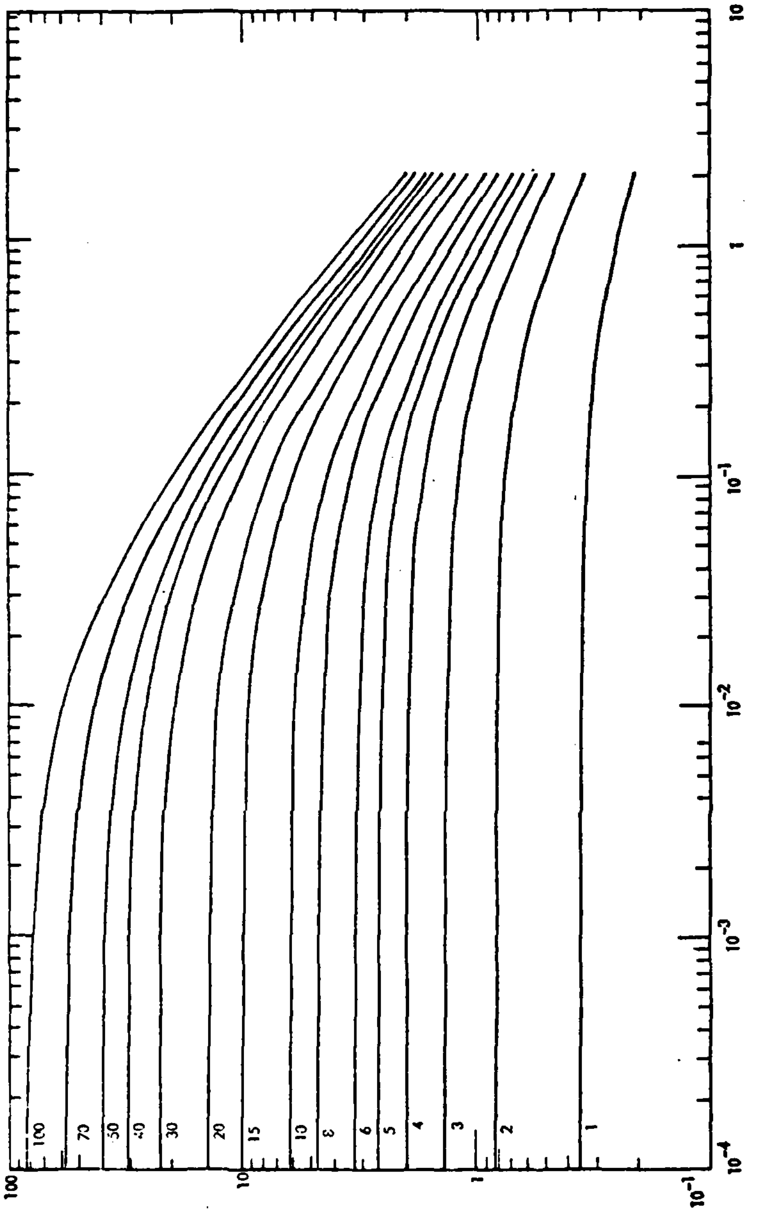
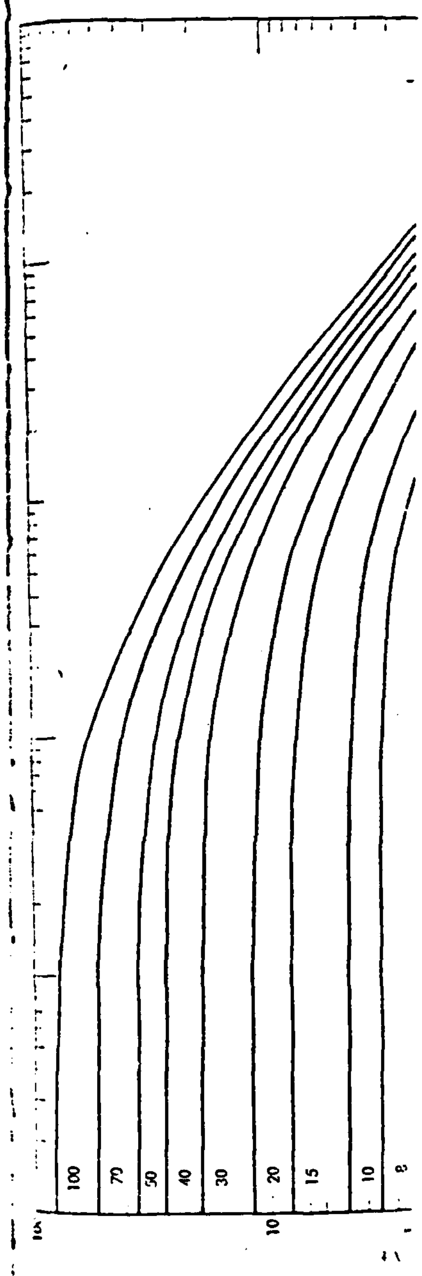


Fig. 3. Spare requirements for initial provisioning with 95 per cent reliability.



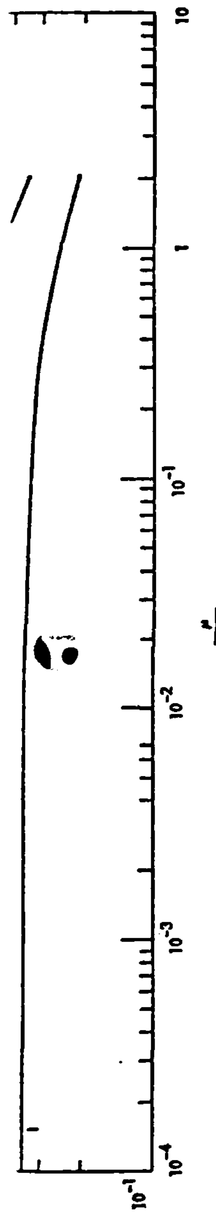


Fig. 3. Spare requirements for initial provisioning with 95 per cent reliability.

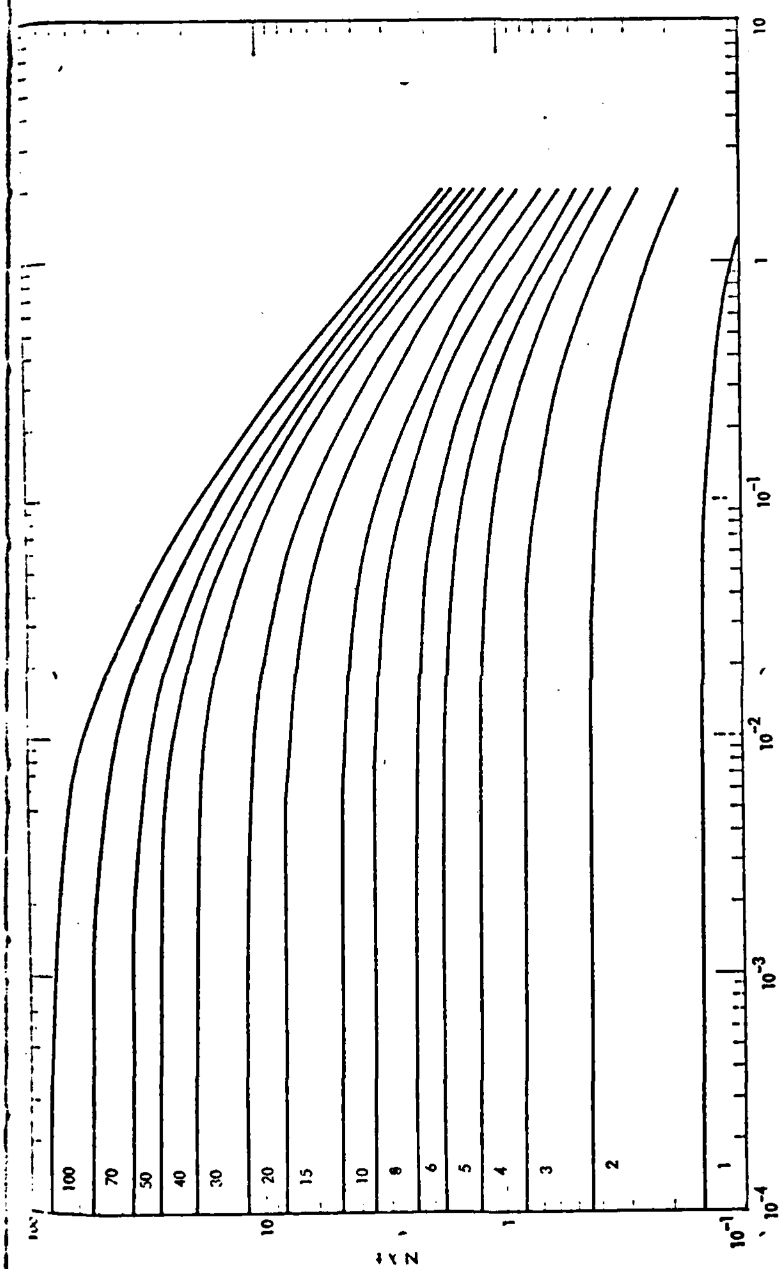


Fig. 4. Spare requirements for initial provisioning with 99 per cent reliability.

Alternately, the curves $R_m(t)=A$ for $m=0(1)39$, $N\lambda/\mu=1(1)40$, and $A=(0.50, 0.60, 0.70, 0.80, 0.90, 0.95, 0.975, 0.99, 0.995, 0.999, 0.9995, 0.9999)$ can be constructed from HARTER's tables of percentage points of the incomplete beta function.[8] These tables give $X(C, D, A)$ for which $I_X(C, D)=A$ for $C=1(1)40$, $D=1(1)40$ and the above values of A. Entering the tables with $C=N\lambda/\mu$, $D=m+1$, and A yields $X(C, D, A)=e^{-\mu t}$ from which $N\lambda t=-C\ln X$ may be obtained.

The system considered in the above example is used for illustrative purposes. Entering the graphs with $((\mu/N\lambda), N\lambda t)=(0.1, 2)$, we see, in agreement with the example, that initial provisioning of 4, 5, and 7 or 8 spares is necessary for system reliabilities of 90, 95, and 99 per cent, respectively.

One defect of the graphs is that they do not yield exact probabilities. In the above example, they show that the reliability with 5 spares is greater than 95 per cent, but do not reveal how much greater. The example showed that $R_5=96$ per cent, somewhat higher than the 95 per cent goal.

On the other hand, the graphs have the merit that the consequence of uncertainty in the values of the failure rates may be easily ascertained. A sensitivity analysis performed via the graphs can be used to help determine where more detailed knowledge is worth the expense necessary to acquire it. For the above example, if nothing were known about μ except that $0\leq\mu\leq\lambda$, then use of Fig. 2 with $N\lambda t=2$ and $\mu/N\lambda$ ranging from 0 to 0.5 reveals that from 4 to 7 or 8 spares are needed to achieve 90 per cent reliability.

Inspection of the graphs reveals that the growth of m^* with μ and t is extremely rapid, and that higher values of μ lead to faster growth of m^* with t:

$$\partial^2 m^*/\partial(\mu/N\lambda)\partial(N\lambda t)>0.$$

It can be shown that for fixed A, $N\lambda$ and $\mu>0$, m^* grows exponentially with t for large t. Equation (B.9) leads to the asymptotic formula

$$m^*\simeq e^{\mu t}F^{-1}(A;(N\lambda/\mu)) \qquad (27a)$$

if t is taken sufficiently large that

$$m^*\gg 1, \qquad N\lambda/\mu; e^{-\mu t}F^{-1}(A;(N\lambda/\mu))\ll 1 \qquad (27b)$$

are satisfied. Here $F^{-1}(A;a)$ is the A-quantile of the standardized gamma distribution with parameter a.

When $\mu=0$, m^* grows asymptotically linearly with t. The normal approximation to the Poisson distribution with large mean leads to

$$A=r_m(t)\simeq\Phi([m-N\lambda t]/\sqrt{N\lambda t}), \qquad (N\lambda t\gg 1)$$

where $\Phi(\cdot)$ is the cumulative function for the standard normal. Hence[7]

$m^*\simeq N\lambda t+$

The exponential growth of m^* w
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A heuristic check on (27a) is
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INSERTION of (21) into (10) leads to t

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applied to (A.1) and (A.2), respective

$R_m(t)=e^{-N\lambda t}[(1-e^{-\mu t})^m/m!]((N\lambda/\mu)-$

and

$1-R_m(t)=e^{-N\lambda t}[(1-e^{-\mu t})^{m+1}/(m+1)$

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$F(a, b; c; z)=$

$$m^* \simeq N\lambda t + \sqrt{N\lambda t}\,\Phi^{-1}(A). \quad (N\lambda t \gg 1;\ \mu = 0) \qquad (28)$$

The exponential growth of m^* with t for $\mu > 0$ (where extra spares are needed to compensate for spare failures) is in sharp contrast to its linear growth when $\mu = 0$.

A heuristic check on (27a) is obtained by differentiation of $R_m(t) = A$ with respect to t (suppressing the asterisk):

$$\partial m/\partial t = (-\partial R_m/\partial t)/(\partial R_m/\partial m(\simeq(-\partial R_m/\partial t)/(R_m - R_{m-1}). \qquad (29)$$

Insertion of (15) leads to the differential equation

$$\partial m^*/\partial t \simeq N\lambda + m^*\mu$$

whose solution is, asymptotically, $m^* \simeq Be^{\mu t}$ where B is independent of t.

APPENDIX A

System Reliability Expressed via Hypergeometric Functions

Insertion of (21) into (10) leads to the desired relation

$$R_m(t) = (e^{-N\lambda t}/m!)((N\lambda/\mu)+1)_m F(-m, (N\lambda/\mu); (N\lambda/\mu)+1; e^{-\mu t}) \qquad (A.1)$$

between system reliability and the hypergeometric function. The identity $I_p(a, b) = 1 - I_{1-p}(b, a)$ leads to an alternate expression of R_m in terms of F:

$$1 - R_m(t) = [(1-e^{-\mu t})^{m+1}/(m+1)!](N\lambda/\mu)_{m+1} F)1 - (N\lambda/\mu), m+1; m+2; 1-e^{-\mu t}). \qquad (A.2)$$

The hypergeometric transformation formulas[5,6]

$$F(a, b; c; z) = (1-z)^{-a} F(a, c-b; c; (z/z-1)),$$

$$F(a, b; c; z) = (1-z)^{c-a-b} F(c-a, c-b; c; z),$$

applied to (A.1) and (A.2), respectively, lead to two more relations,

$$R_m(t) = e^{-N\lambda t}[(1-e^{-\mu t})^m/m!]((N\lambda/\mu)+1)_m F(-m, 1; (N\lambda/\mu)+1; -e^{-\mu t}/(1-e^{-\mu t})), \qquad (A.3)$$

and

$$1 - R_m(t) = e^{-N\lambda t}[(1-e^{-\mu t})^{m+1}/(m+1)]!(N\lambda/\mu)_{m+1} F(m+1+(N\lambda/\mu), 1; m+2; 1-e^{-\mu t}) \qquad (A.4)$$

The first transformation formula applied to (A.4) leads to

$$1 - R_m(t) = e^{-(N\lambda-\mu)t}[(1-e^{-\mu t})^{m+1}/(m+1)]!(N\lambda/\mu)_{m+1} F)1 - (N\lambda/\mu), 1; m+2; 1-e^{\mu t}). \qquad (A.5)$$

The usefulness of these expressions for manipulative purposes is demonstrated next, while their usefulness for asymptotic expansions is shown in Appendix B.

The hypergeometric function possesses the Maclaurin series expansion

$$F(a, b; c; z) = \sum_{n=0}^{n=\infty} [(a)_n(b)_n/(c)_n](z^n/n!) \qquad (A.6)$$

generally convergent for $|z|<1$ but which breaks off if the parameter a is a negative integer. Maclaurin series expansions of (A.1) and (A.3) are precisely (18) and (3b). If the identity

$$F(a, 1; c; z) = 1 + (az/c)F(a+1, 1; c+1; z) \tag{A.7}$$

[which follows from (A.6)] is inserted into (A.4), the result is (16). This completes the proof of the equivalence of (3b), (18), (20), and (10). It is noteworthy that (3b), (18), and (20) are three distinct sums, the proof of whose equivalence is otherwise nontrivial.† Finally, the identity [5,6]

$$(a)_n z^{a-1} F(a+n, b; c; z) = (d^n/dz^n)[z^{a+n-1} F(a, b; c; z)],$$

when evaluated at $(a, b, c, z, n) = (-m, (N\lambda/\mu), (N\lambda/\mu)+1, e^{-\mu t}, 1)$ and combined with (A.1), leads to an alternate derivation of (15).

APPENDIX B

Asymptotic Expansions for System Reliability

System reliability for small t may be obtained by Maclaurin series expansion of (A.2) with the result

$$\begin{aligned} 1-R_m(t) &= [(N\lambda/\mu)_{m+1}/m!] \textstyle\sum_{k=0}^{k=\infty} (1-(N\lambda/\mu))_k (1-e^{-\mu t})^{k+m+1}/[(m+k+1)k!] \\ &= [(\mu t)^{m+1}/(m+1)!](N\lambda/\mu)_{m+1}\{1-(m+1)(m+2)^{-1}[N\lambda+(m\mu)/2)]t+O(t^2)\}. \\ &\qquad (t \ll 1/N\lambda,\ 1/\mu;\ m=0, 1, 2, \cdots) \end{aligned} \tag{B.1}$$

System reliability for large t may be obtained by Maclaurin series expansion of (A.1), with the result, for $\mu>0$,

$$R_m(t) = (e^{-N\lambda t}/m!)((N\lambda/\mu)+1)_m\{1-[mN\lambda/(N\lambda+\mu)]e^{-\mu t}+O(e^{-2\mu t})\}. \tag{B.2}$$

System reliability for small spare failure rate μ may be expanded in a Maclaurin series in $y=\mu/N\lambda$. Insertion of

$$(N\lambda/\mu)_k = (N\lambda/\mu)^k\{1+[(k-1)k/2]y+[(3k-1)(k-2)(k-1)k/24]y^2+O(y^3)\}$$

and

$$(1-e^{-\mu t})^k = (\mu t)^k\{1-(k/2)\mu t+[k(3k+1)/24](\mu t)^2+\cdots\}$$

into (20) leads, after much simplification, to the expansion

$$\begin{aligned} R_m(t) = r_m(t) - [e^{-N\lambda t}(N\lambda t)^{m+1}(2(m-1)!)^{-1}]y\{1+(y/12)[(m-1)(3m+2) \\ -(3m+1)N\lambda t]+O(y^2)\} \quad (m=1, 2, 3, \cdots) \end{aligned} \tag{B.3}$$

$$y=\mu/N\lambda \ll (1/m^2);\ \mu t \ll 1/m,$$

where r_m is given by (4).

$R_0=r_0$ while, for $m \geqq 1$, a necessary condition on the magnitude of μ for the approximation $R_m(t) \simeq r_m(t)$ to be valid is that

$$\mu/N\lambda \ll 2(m-1)!\,r_m(t)/e^{N\lambda t}(N\lambda t)^{m+1} = 2r_m(t)/\{m(m+1)[r_{m+1}(t)-r_m(t)]\}. \tag{B.4}$$

† A direct proof of the equivalence of (10), (18), and (20) is given in reference 8, pp. vii–viii.

System reliability for large numbers of spares may be obtained via the asymptotic expansion (reference 5, equation 15.7.1)

$$F(a, b, c, z) = 1 + (ab/c)z + \cdots + [(a)_n(b)_n/(c)_n](z^n/n!) + O(1/|c|^{n+1}). \qquad \text{(fixed } a, b, z; |c| \to \infty; n = 1, 2, 3, \cdots) \tag{B.5}$$

If (B.5) is applied to (A.5), the result is

$$1 - R_m(t) = [e^{-(N\lambda-\mu)t}(1-e^{-\mu t})^{m+1}/(m+1)!](N\lambda/\mu)_{m+1} \left\{ \{1 + [(N\lambda/\mu) - 1]/(m+1)\} (e^{\mu t} - 1) + O(1/m^2) \right\}. \tag{B.6}$$

If μ approaches zero in the above, the asymptotic expansion for the complementary cumulative Poisson probability is obtained:

$$1 - r_m(t) = [(N\lambda t)^{m+1}/(m+1)!]e^{-N\lambda t}\{1 + [N\lambda t/(m+2)] + O(1/m^2)\}. \tag{B.7}$$

If, on the other hand, $N\lambda/\mu$ is integral, (B.6) reduces correctly to the asymptotic expansion of the complementary cumulative binomial probability.

If μ is bounded away from zero, Stirling's approximation for the gamma function leads to

$$\Gamma((N\lambda/\mu) + m + 1)/(m+1)! = m^{(N\lambda/\mu)-1}[1 + O(1/m)]. \qquad (m \gg 1, N\lambda/\mu)$$

The expansion in (B.6) becomes

$$1 - R_m(t) = [e^{-(N\lambda-\mu)t}/\Gamma(N\lambda/\mu)]m^{(N\lambda/\mu)-1}(1-e^{-\mu t})^{m+1}[1 + O(1/m)]. \qquad (m \gg 1, N\lambda/\mu) \tag{B.8}$$

When $N\lambda = \mu$, (B.8) reduces correctly to $1 - R_m(t) \simeq (1 - e^{-\mu t})^{m+1}$.

System reliability for large m and t may be obtained from (10) and (11). Stirling's approximation leads to

$$R_m(t) \simeq \frac{m^{N\lambda/\mu}}{\Gamma(N\lambda/\mu)} \int_0^{e^{-\mu t}} dx\, x^{(N\lambda/\mu)-1}(1-x)^m. \qquad (m \gg 1, N\lambda/\mu)$$

The approximation $(1-x)^m \simeq e^{-mx}$ is valid for $0 \leqq x < 1$ if $mx^2 \ll 1 - x$. With the change of variables $x = y/m$, the above becomes

$$R_m(t) \simeq \int_0^{me^{-\mu t}} dy\, y^{N\lambda/\mu - 1}e^{-y}/\Gamma(N\lambda/\mu) = F(me^{-\mu t}; N\lambda/\mu), \qquad (m \gg 1, N\lambda/\mu; me^{-2\mu t} \ll 1) \tag{B.9}$$

where $F(\cdot; a)$ denotes the cumulative standardized gamma function with parameter a.

APPENDIX C

Techniques for Calculation of System Reliability

Several methods of calculation of the system reliability $R_m(t)$ are tabulated below. Of these, equation (20) appears best suited for computer evaluation.

1. If $N\lambda/\mu$ is an integer, R_m may be obtained via (5), through lookup in a table of cumulative binomial probabilities.
2. If $\mu/N\lambda$ is small, R_m may be obtained via (B.3), through lookup in a table of cumulative Poisson probabilities, with correction terms if necessary.
3. If m is not too large, R_m can be obtained via (10), through lookup in a table[3] of the incomplete beta function.
4. Weiss gives [1] a normal approximation to the incomplete beta function if m and $N\lambda/\mu$ are both large. (B.9) gives a gamma approximation for large m and t. Additional approximations are given in reference 5.
5. Three closed expressions, (3b), (18), and (20), represent R_m as the sum of $m+1$ terms. As Harter[6] points out, (18) is useless for numerical computation if m is large due to near-cancellation of the oscillating terms. Of the two remaining sums, both of which have positive summands, (20) is much preferred for the following reasons: (a) the summand has a simpler appearance and can be obtained recursively via (17); (b) even more important, the summands are independent of m so that a whole sequence of R_m's can be quickly generated by merely adding more and more summands. This procedure is numerically stable since the summands eventually decrease in magnitude. This feature is extremely useful if one wants the minimum number of spares m for which $R_m \geqq A$ is satisfied; (c) if R_m is obtained via (20), then the quantities $R_m - R_{m-1}$ and, by (15), dR_m/dt are available as by-products. The last quantity is needed, for example, if Newton's method is used to find the value of t, for fixed m and A, for which $R_m(t) = A$.

ACKNOWLEDGMENT

THIS RESEARCH was initiated during the author's employment at Airborne Instruments Laboratory, Deer Park, New York. The author wishes to thank MR. MARVIN GOLDSTEIN of AIL for encouragement and numerous discussions.

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LOAD LIST MANUAL

NAVY FLEET MATERIAL SUPPORT OFFICE

MECHANICSBURG, PA. 17055

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I

INTRODUCTION

The Navy has the mission of strategic deterrence, sea control, projection of power, and overseas presence. In order to perform this mission, adequate material support is required. This material support takes place at three levels: the Organic Level of Supply; the First Echelon of Resupply; and the Second Echelon of Resupply.

The three levels of material support

The Organic Level of Supply is the material carried on board the individual ship. It is defined by the various allowance lists that designate the items and their quantities that the ship should carry in order to be self-sustaining for a specified period of time.

The First Echelon of Resupply is the material on board the ships of the Mobile Logistic Support Force (MLSF) and at selected shore activities (e.g., Submarine Bases Pear Harbor and New London). The ships of the MLSF consist of Combat Store Ships, Destroyer Tenders, Submarine Tenders, and Repair Ships. The MLSF has the responsibility of providing the Operating Forces with resupply and repair support at sea. It is this level of support that is the concern of this manual.

The Second Echelon of Resupply is the Navy's wholesale system. It is that material managed by the two Inventory Control Points, the Aviation Supply Office and the Ships

Parts Control Center, and stored at supply centers, supply depots, air stations, weapon stations, and shipyards.

PURPOSE OF THE UICP LOAD LIST OPERATIONS

UICP and Load List

The UICP Load List operations are designed to determine the variety of items (the range) and the quantity of each item (the depth) that should be included on MLSF loads. In making the necessary computations, the operations consider the desired degree of support, the expected demand for the items, and the special circumstances related to new or critical equipments.

The Load List operations begin with a specification by the Chief of Naval Operations (CNO) of the desired degree of support. This specification is in terms of the percentage of units or requisitions that is to be satisfied by the load and is called the "effectiveness."

The UICP Load List operations then estimate the pattern of demand for each item expected over the period of interest. This estimate of demand is either based on historical demand which may be adjusted for a projected tempo of operations or related to an item's population and expected failure rate.

Once the pattern of demand is estimated, the load quantity needed to meet that demand with the required degree of effectiveness is computed.

After all items have been examined and special considerations have been incorporated into the operations, the effectiveness of the load is computed. If the computed effectiveness does not meet the required effectiveness, various parameters are adjusted and the computations are repeated until the requirement is met.

THE DATA USED IN THE LOAD LIST COMPUTATIONS

Load List Data

The data required to determine the quantity of an item to be included on a Load List can come from three different sources: historical demand data, population and failure data from the ICP files, and technical overrides. The ICP files and the FMSO Navy Management Data File (NMDF) provide the Load List operations with the necessary management data for the items. A chapter of the manual has been devoted to each of the three sources of data so they merely will be introduced in this section.

Historical Demand Data

Collecting demand

The Mobile Logistic Support Force Demand Collection Program provides for the monthly collection of fleet demand documents from reporting activities and maintains a file of the most recent 24 month's demand data. These demand data are in terms of peacetime operations and, in the Load List computations, may have to be increased to expected wartime levels and adjusted for the desired support period.

Inventory Control Point Files

The Ships Parts Control Center maintains three files that interact with the Load List operations. The Load List operations use these three files in deriving demand estimates for Tender and Repair Ship Load Lists only. (We will discuss the types of load lists in the next section.)

Weapon Systems File

The first of the files is the Weapon Systems File (WSF). The WSF is constructed in three levels: A, B, and C. Level A data concerns end use weapons; such as ships or aircraft. Level B contains data regarding particular systems contained in these end use weapons. Equipments, components, and specific parts are included in Level C of the WSF. Linkages are maintained between the three levels so that a weapon can be broken down into its systems, equipments, components, and parts. Through this breakdown, population data for the individual items can be derived.

Master Data File

The second SPCC file is the Master Data File (MDF). The MDF contains a record for each item managed by SPCC. The item record includes a number of data elements used in the Load List operations, both as Management data and as inputs to the computations. Of particular interest to the range and depth computations is the Best Replacement Factor, the expected annual replacement rate for an item.

Program Support Interest File

The final SPCC file is the Program Support Interest File (PSI). This file contains those items for which SPCC has program support but not supply management responsibility. It is similar to the MDF and is, again, a source of Load List data including the Best Replacement Factor.

If the population data from the WSF, MDF, and PSI are factored by the BRF, an estimate of annual demand can be obtained.

Technical Overrides

Overrides

The Load List range and depth computations can be impacted by a third source of data, the Technical Override. Overrides can be used to add or exclude items from the range of a Load List and to increase or decrease the computed depth for an item. The use of overrides is carefully controlled and, in the case of those that establish a mandatory or minimum load quantity, are confined (generally) to new or critical equipments.

TYPES OF LOAD LISTS

FIRL

There are two distinct Load List operations conducted by FMSO. The first of these is the preparation of a Fleet Issue Requirements List which represents the projected material requirements for the surface ship resupply mission of the AFS

Combat Store Ships. The second operation is the building of Tender and Repair Ship Load Lists. These lists represent the projected material requirements for the industrial (repair) missions of Destroyer Tenders (AD), Repair Ships (AR), and Submarine Tenders (AS) as well as the resupply mission of Submarine Tenders.

TARSLL

Fleet Issue Requirements List (FIRL)

There are two FIRLs, one for the Atlantic Fleet (LANTFIRL) and one for the Pacific Fleet (PACFIRL). Each FIRL is updated annually and represents the computed range and depth of material needed to support the Fleet under a projected wartime environment for a designated period of time. The computations are based on 24 months of historical demand suitably factored for wartime tempo and the length of the required support period. The computations can be overridden in certain approved situations and items can be added to or deleted from the range and increases or decreases can be made to an item's depth.

That part of the FIRL that is on a particular AFS or at a designated shore base is called the Fleet Issue Load List (FILL). In a given Fleet, the FILLs for all resupply elements will be the same. The FILL range and depth are based on the deployed requirements of the fleet while those of the FIRL are based on the expanded requirements. The

FILL

expanded requirements include the demands from deployed surface ships plus all stock point fleet issue demands from non-deployed ships.

There are currently four FILLs in the Atlantic Fleet:

AFS 2	USS Sylvania
AFS 5	USS Concord
AFS 6	USS San Diego
Ashore	NSC Norfolk

and five in the Pacific

AFS 1	USS Mars
AFS 3	USS Niagara Falls
AFS 4	USS White Plains
AFS 7	USS San Jose
Ashore	NSD Subic Bay

The frequency of demand or expensiveness of an item may make it undesirable to include it on each FILL but yet it is felt essential to the FIRL. These items are classified as FIRL Only and are positioned at NSC Norfolk for the LANTFIRL and NSD Subic Bay for the PACFIRL.

Tender and Repair Ship Load List (TARSLL)

A TARSLL is developed for a tender based on the equipment carried on board the ships for which it is responsible.

The range and depth of a TARSLL is computed from experienced demand reported by tenders and repair ships and, in the absence of demand data, the installed population, and estimates of failure rates.

Type of TARSLL

A TARSLL may be ship-tailored or ocean-tailored. A ship-tailored (sometimes called hull-tailored) TARSLL is prepared for a specific tender or repair ship and contains the material required for it to support its assigned ships (hulls). Presently, ship-tailored TARSLLs are constructed for those ships/activities supporting submarines.

An ocean-tailored TARSLL is a load placed on all tenders or repair ships of a particular class in a particular fleet to support specific hull types. For example, a Destroyer Tender (AD) TARSLL might be prepared for the Atlantic Fleet.

Type of items

The items carried on a TARSLL for the tenders industrial mission consist of equipment-related and non-equipment-related items. Equipment-related items are the repair parts required to repair the equipment carried by the ships being tended. Non-equipment-related items are that material required by the tender to carry out its maintenance functions.

The current list of afloat MLSF ships that carry FMSO prepared TARSLLs are:

Destroyer Tenders (Ocean Tailored, Industrial Mission)

Atlantic Fleet

AD 17	Piedmont
AD 18	Sierra
AD 19	Yosemite
AD 26	Shenandoah
AD 38	Puget Sound

Pacific Fleet

AD 14	Dixie
AD 15	Prairie
AD 36	Bryce Canyon
AD 37	Samuel Gompers

Submarine Tenders (Ship Tailored, Industrial and Resupply Mission)

Atlantic Fleet

AS 11	Fulton
AS 16	Gilmore
AS 18	Orion
AS 31	Hunley (FBM)
AS 32	Holland (FBM)
AS 33	Simon Lake (FBM)
AS 34	Canopus (FBM)
AS 36	L.Y. Spear

Pacific Fleet

AS 12	Sperry
AS 19	Proteus (FBM)
AS 37	Dixon

Repair Ships (Ocean Tailored, Industrial Mission)

Atlantic Fleet

AR 5	Vulcan
AR 28	Grand Canyon

Pacific Fleet

AR 6	Ajax
AR 7	Hector
AR 8	Jason

The Load List quantities for tenders and repair ships other than FBM tenders are based on anticipated wartime requirements and are designated part of the Prepositioned War Reserve Stock. (Note: This designation results from authorization from OPNAV and should not be confused with PWRS in the ICP PPR File.) For FBM tenders, the Load List quantities are based on peacetime demand and are designated Peacetime Operating Stock.

Supplements to the Load Lists

FBM Load Lists will also include items related to Strategic Systems Project Office equipments. In almost every instance, these items will be included as a result of an override. A special Weapon System Supplement contains SSPO equipment support.

Weapon System Supplement

FILES USED IN PREPARING LOAD LISTS

There are a number of files used in preparing Load Lists in addition to the ICP files discussed earlier. In this section, we are going to briefly describe the major files.

Mobile Logistic Support Force (MLSF) Master Demand File

This most important file contains a history of the most recent 24 months of MLSF demands as reported to FMSO as well as surface ship requisitions from selected shore activities and submarine demand from Submarine Bases New London and Pearl Harbor. These demands will include:

Master Demand File

1. Fleet issues for first echelon resupply.

2. Demands from tenders and repair ships for material used in repairing ships.

The construction of a FIRL/FILL will use only the surface ship fleet issue demands. The construction of a TARSLL will use the demands generated by tenders and repair ships in their industrial mission and by submarine tenders in their resupply mission.

The demand is identified by National Item Identification Number (NIIN), Reporter Unit Identification Code (UIC), Reporting Date, Requestor UIC, and Project Code.

Navy Management Data File (NMDF)

The other files

This file contains descriptive information regarding each NIIN considered for Load Lists. This information includes the item's price, unit of issue, Cognizance Symbol, special handling instructions, and storage requirements.

NMDF Addendum File

This file ensures that the Load List operation will be using the most current NIIN at all times. The file cross references superseded NIINs to current NIINs. At the time of Load List construction, the NIINs of the candidates are compared to the superseded NIINs on this file. If a match is made, the candidate's record is updated to the current NIIN.

FIRL Master Atlantic (Pacific) File

This file contains a record of the most recently constructed Atlantic or Pacific FIRL/FILL. The record for each item contains not only the Load List quantities and the necessary management data but also the demand and demand frequency data that were used in computing the load quantities.

Load List Master File

There will be a Load List Master File for each TARSLL. It is similar to the FIRL Master File in that it contains management data and the Load List quantities. Each item record may include population data, and demand quantities, frequencies, and forecasts.

LOAD LIST EFFECTIVENESS

The objective of a Load List is to meet the demands of the units of the Fleet it supports in terms of both the range of items requested and the quantity of each item requested. Prior to the construction of a Load List, this objective is specified by CNO and expressed in terms of effectiveness. After the construction of the Load List, a determination can be made of how well the load satisfies expected demand. This determination is also in terms of effectiveness.

We, thus, have two values of effectiveness: the objective or goal and the result of the Load List computations. The entire purpose of the UICP Load List operations is to construct the load so that the computed effectiveness meets the objective. If the computed effectiveness is too low, the range and depth of the load is deficient in meeting the requirements of the Fleet. If the computed effectiveness is too high, it means that the range is too broad or the depth too deep and more funds are being expended on the load than are required.

Net and Gross Effectiveness

Throughout the manual, we will be talking about several different measures of effectiveness. One distinction is between Net and Gross Effectiveness. Net Effectiveness measures how well the load meets the demand for items on the load itself. Gross Effectiveness is how well the load meets the demand for all items, whether they are included in the range of the load or not.

Unit and Requisition Effectiveness

Effectiveness can also be measured in terms of units satisfied or requisitions satisfied. When we talk of Unit Effectiveness, we are talking of the fraction of the total quantity of units demanded that were satisfied. With Requisition Effectiveness, we mean the fraction of the total number of requisitions submitted that were satisfied.

OUTPUTS OF THE LOAD LIST OPERATIONS

The Load List operations produce two basic outputs; the Supply Management Aid Records and the publication applicable to a particular Load List, and numerous statistics.

Supply/Management Aid Records

A Supply/Management Aid Record (SMAR) contains management data and the load list quantities for each item on the load. A SMAR may be produced by either the FIRL/FILL operation or the TARSLL operation. The SMARs for the two operations are very similar, differing in only several data elements.

Supply/Management Aid Records are distributed to the MLSF ships or activities associated with a particular load. SMARs may be revised at times other than those of normal load list construction or revision.

Load List Publications

The FMSO Load List production effort results in two distinct publication types. There is one set for the FIRL/FILL outputs and another set for the TARSLL outputs.

The loads developed by the FIRL/FILL operation are published as Chapter IV of the Consolidated Afloat Requisitioning Guide, Overseas (CARGO). Chapter IV of the CARGO is the major portion of the publication and the only one produced by FMSO. However, FMSO is responsible for the publication and distribution of the entire CARGO and the other contributors forward their chapters to FMSO in reproducible form.

CARGO

Two CARGOs will be published, one for the Atlantic Fleet and one for the Pacific Fleet. Each will be published annually, corresponding to the annual construction of the FIRL/FILL. Quarterly supplements of each CARGO will be produced, containing changes to all chapters with FMSO responsible for preparing the changes to Chapter IV.

An example page from a CARGO (Chapter IV) is shown on the next page.

Formal publications are produced for each of the TARSILLs. These may be entitled Destroyer Tender (AD) Load List, Repair Ship (AR) Load List (as the result of a recent change, these two publications are being combined), FBM Submarine Tender Load List, or Non-FBM Submarine Tender Load List.

An example page from one of these publications is shown on page 1-19.

ATLANTIC FLEET ISSUE LOAD LIST—NIIN SEQUENCE

ITEM	COG	NSN	SMC	ITEM NAME	U/I	U/PRICE	U/CUBE	NOTES	SEL	ABD	ABG
3041	9Q	5350-00-193-1340		LAPPING AND GRIND	CN	1.02	.0000				I
3042	9Q	5350-00-193-1341		LAPPING AND GRIND	CN	.04	.0000				I
3043	9Q	5350-00-193-1340		LAPPING AND GRIND	CN	1.04	.0000				I
3044	1H	5350-00-193-1344		LAPPING AND GR	EA	3.80	.0000				I
3045	1H	4130-00-193-2047		FILTER ELEMENT,AI	EA	13.00	.0000			A	
3046	9C	4730-00-193-2716		NIPPLE,PIPE	EA	1.04	.0200				I
3047	9G	6350-00-193-2794		BUZZER	EA	1.10	.0620			A	
3048	9N	5960-00-193-5085		ELCTR TB 0034	EA	4.43	.0170	R B			
3049	9N	5960-00-193-5087		ELCTR TB 1836T	EA	1.61	.0170				
3050	9N	5960-00-193-5081		ELCTR TB 1826A	EA	00.00	.0290	R B			
3051	9N	5960-00-193-5092		ELECTRON TUBE	EA	53.10	.0170	R B		A	
3052	9N	5960-00-193-5120		ELCTR TB 2050R	EA	8.42	.0170				
3053	9N	5960-00-193-4111		ELCTR TB 9656	EA	15.40	.0030				
3054	9N	5960-00-193-5119		ELECTRON TUBE	EA	3.70	.0030			A	
3055	9N	5960-00-193-5110		ELECTRON TUBE	EA	2.00	.0090			A	
3056	9Q	5350-00-193-7297		LAPPING AND GRIND	CN	.01	.0000				I
3057	9Z	5310-00-193-7501		WASHER,FLAT	HD	.42	.0020				I
3058	9N	5950-00-193-8668		TRANSFORMER,POWER	EA	26.70	.0070				
3059	9Z	5310-00-193-9600		WASHER,FLAT	EA	.02	.0100				I
3060	9Z	5310-00-193-9793		WASHER,FLAT	EA	.03	.0100				I
3061	9Z	5365-00-193-9817		SPACER,RING	EA	.03	.0010				
3062	9Z	5310-00-194-0877		WASHER,FLAT	EA	.04	.0010				I
3063	9G	6685-00-194-1710		THERMOMETER,INDIC	EA	20.90	.0000				
3064	9N	5935-00-194-3041		JACK,TELEPHONE	EA	1.97	.0090			A	I
3065	9Z	5330-00-194-3705		PACKING,PREFORMED	EA	.11	.0010				I
3066	9Z	5330-00-194-3704		PACKING,PREFORMED	EA	.06	.0010				I
3067	9Z	5330-00-194-3710		PACKING,PREFORMED	EA	.07	.0320				I
3068	9Z	5330-00-194-3711		PACKING,PREFORMED	EA	.12	.0020				I
3069	9Z	5330-00-194-3712		PACKING,PREFORMED	EA	.10	.0010				I
3070	9Z	5330-00-194-3713		PACKING,PREFORMED	EA	.10	.0010				I
3071	9Z	5330-00-194-3719		PACKING,PREFORMED	EA	.27	.0010				
3072	9Z	5330-00-194-3720		PACKING,PREFORMED	EA	.11	.0000				I
3073	9Z	5330-00-194-3726		PACKING,PREFORMED	EA	.17	.0100				I
3074	9Z	5330-00-194-3729		PACKING,PREFORMED	EA	.15	.0010				
3075	9Z	5330-00-194-3734		PACKING,PREFORMED	EA	.92	.0010				
3076	9Z	5330-00-194-3737		PACKING,PREFORMED	EA	.14	.0100				I
3377	9G	6250-00-194-6708		STARTER,FLUORESCE	EA	.09	.0010				I
3078	9G	6250-00-194-6799		STARTER,FLUORESCE	EA	.44	.0020				I
3079	9G	5940-00-194-7304		FERRULE,ELECTRICA	HD	12.10	.0120				I
3080	9G	6240-00-194-7924		LAMP,INCDT 79W	EA	.31	.0150				I
3081	9G	5975-00-194-8870		JUNCTION BOX	EA	.96	.0150				I
3082	9G	5975-00-194-8871		JUNCTION BOX	EA	.46	.0200				I
3083	9G	5975-00-194-8878		JUNCTION BOX	EA	.38	.0100				I
3084	9Z	6145-00-194-9840		BRAID,WIRE	FT	.12	.0010				I
3085	9N	5905-00-195-2312		RESISTOR,VARIABLE	EA	2.94	.0170				I
3086	9Y	6140-00-195-5341		BATTERY,STORAGE	EA	69.40	.0000			A	I
3087	9N	5905-00-195-5520		RESISTOR,FIXED,CO	EA	.13	.0090				I
3088	9N	5905-00-195-6794		RESISTOR,FIXED,CO	EA	.14	.0090				I
3089	9N	5905-00-195-6824		RESISTOR,FIXED,CO	EA	.10	.0090				I
3090	9N	5905-00-195-8450		RESISTOR,VARIABLE	EA	4.57	.0010			A	I
3091	9N	5910-00-195-8716		CAPACITOR,FIXED,E	EA	1.44	.0170			A	
3092	9N	5999-00-195-9480		CLIP,ELECTRICAL	PG	1.40	.0000				
3093	9C	3020-00-196-0803		CHAIN,ROLLER	FT	1.44	.0070				
3094	9C	4730-00-196-0930		BUSHING,PIPE	EA	.43	.0100				I
3095	9C	4730-00-196-1972		NIPPLE,PIPE	EA	.93	.0010				I
3096	9C	4730-00-196-1981		NIPPLE,PIPE	EA	.80	.0100				I
3097	9C	4730-00-196-1990		NIPPLE,PIPE	EA	.46	.0100				I
3098	9C	4730-00-196-1992		NIPPLE,PIPE	EA	.61	.0710				I
3099	9D	8405-00-196-2280		TROUSERS,MEN	PR	5.98	.0000				
3100	9D	8405-00-196-2281		TROUSERS,MEN	PR	5.98	.0000				
3101	9G	5940-00-196-2289		TERMINAL,QUICK DI	EA	5.04	.0010				
3102	1H	5935-00-196-2292		JACK,TIP	EA	20.90	.0060			A	I
3103	1H	5935-00-196-2293		PLUG,TIP	EA	20.90	.0000				I
3104	9D	8405-00-196-2302		TROUSERS,MEN	PR	5.98	.0000				
3105	9N	5999-00-196-2862		CONTACT,ELECTRICA	EA	5.01	.1710				
3106	9N	5999-00-196-2881		CONTACT,ELECTRICA	EA	3.11	.0010			A	
3107	9N	5999-00-196-2988		CONTACT,ELECTRICA	EA	6.81	.0040				
3108	9Z	5330-00-196-5322		PACKING,PREFORMED	EA	.14	.0020				
3109	9Z	5330-00-196-5337		PACKING,PREFORMED	EA	.79	.0000				
3110	9Z	5330-00-196-5339		PACKING,PREFORMED	EA	.42	.0010				I
3111	9Z	5330-00-196-5341		PACKING,PREFORMED	EA	.96	.0020				I
3112	9Z	5330-00-196-5351		PACKING,PREFORMED	EA	.45	.0070				I
3113	9Z	5330-00-196-5388		PACKING,PREFORMED	EA	.04	.0010				
3114	9Z	5330-00-196-5381		PACKING,PREFORMED	EA	.08	.0010				I
3115	9Z	5330-00-196-5382		PACKING,PREFORMED	EA	.06	.0010				I
3116	9Z	5330-00-196-5389		PACKING,PREFORMED	EA	.06	.0010				I
3117	9Q	7340-00-197-1271		KNIFE,BONING	EA	2.79	.0000				I
3118	9G	5940-00-197-3351		TERMINAL,LUG	HD	5.06	.0120				
3119	9Z	5310-00-197-4169		WASHER,FLAT	EA	.05	.0100				I
3120	9N	5905-00-197-4280		RESISTOR,FIXED,FI	EA	.49	.0030				I

ORGANIZATIONAL RESPONSIBILITIES

These are a number of organizations that contribute to the development of a Load List. Their contribution may take the form of introducing data, reviewing the output, and developing and implementing the Load List operations. A discussion of the major areas follows.

FMSO Responsibilities

The Fleet Material Support Office has a number of interactions with the Load List process. First, FMSO's Systems Design and Procedures Department is responsible for the development of the computer programs used in the Load List process. These programs are based on mathematical models generated by FMSO's Operations Analysis Department.

The organization with the primary responsibility for the production of Load Lists is the Load List Branch of the Comptroller Department of FMSO. Here is where the demand data is collected and verified, the Program Management Plan is prepared, the Load List process is managed, and the outputs are published.

COG	STOCK NUMBER	SM IC	ITEM NAME	U/I	UNIT PRICE	N/CUBE	LOAD QTY	A	B	C	D	E F	G
9C	4720 000331891		HOSE ASSEMBLY	AY	73.84	.0000	1	1	U		0	00	
9C	4720 000331895		HOSE ASSEMBLY	AY	288.08	.0000	1	1	U		0	00	
9C	4310 000332007		VALVE PLATE ASSY	EA	69.48	.0000	1	1	U		0	00	
9C	4210 000332761		HOSE ASSEMBLY,NONME	EA	96.64	.0000	1	1	U		0	00	
9C	4210 000332763		HOSE ASSEMBLY,NONME	EA	178.88	.0000	1	1	U		0	00	
9C	4210 000332768		ADAPTER,TWIN NOZZLE	EA	8.16	.0000	1	1	U		0	00	
9G	5977 000333624		BRUSH,ELECTRICAL CO	EA	.72	.0020	8	4	U		0	00	
9N	5935 000335654		CONNECTOR,RECEPTACL	EA	3.83	.1000	1	1	U		0	00	
9N	5935 000335653		CONNECTOR,RECEPTACL	EA	4.62	.0090	1	1	U		0	00	
9Z	5330 000340524		GASKET	EA	2.12	.0040	7	1	U		0	00	
9N	5999 000340574		CAP,ELECTRICAL	EA	.08	.0100	2	1	U		0	00	
9Z	5330 000340600		GASKET	EA	.40	.0200	34	1	U		0	00	
9Z	5310 000340612		WASHER,FLAT	EA	.55	.0000	18	1	U		0	00	
9Z	5330 000340737		GASKET	EA	1.28	.0020	18	1	U		0	00	
9C	2910 000343018		GAGE,VALVE INJECTOR	EA	6.48	.0010	92	1	U		0	00	
9N	5015 000347692		SPRING	EA	.09	.0000	23	1	U		0	00	
9N	5815 000347690		CORD ASSEMBLY	EA	1.74	.0000	4	1	U		0	00	
9N	5015 000347690		BRACKET	EA	1.55	.0000	9	1	U		0	00	
9C	4320 000357370		IMPELLER,PUMP	EA	51.48	.0420	1	1	U		0	00	
9C	4310 000357514		STRIP,VALVE	EA	1.72	.0108	64	16	U		0	00	
9C	4310 000357518		STRIP,VALVE	EA	.85	.0100	6	6	U		0	00	
1H	9505 000357535		WIRE,NONELECTRICAL	EA	2.40	.0000	96	24	U		0	00	M
9C	4820 000357610		VALVE,REGULATING,FL	EA	79.04	.0000	1	1	U		0	00	
9C	4730 000357709		STRAINER ELEMENT,SE	EA	42.02	.0000	1	1	U		0	00	
9N	5999 000357811		CONTACT,ELECTRICAL	EA	12.81	.0030	6	4	U		0	00	
9N	5999 000357812		CONTACT,ELECTRICAL	EA	10.01	.0100	6	4	U		0	00	
9N	5999 000358182		CONTACT,ELECTRICAL	EA	1.14	.0100	80	20	U		0	00	
9C	4320 000358922		SHAFT ASSEMBLY,PUMP	EA	97.76	.1490	9	1	U		0	00	
1H	6650 000359207		FILTER,DIDYMIUM	EA	15.00	.0008	4	1	U		0	00	M
1H	6650 000359208		FILTER,POLAROID	EA	43.50	.0008	1	1	U		0	00	M
9C	4210 000359489		TUBE ASSEMBLY,BASOR	EA	8.54	.0000	1	1	U		0	00	
1H	4820 000359680		DIAPHRAGM,VALVE,FLA	EA	19.50	.0000	1	1	U		9	XX	M
9C	4820 000360021		SEAT,VALVE	EA	14.14	.0000	1	1	U		0	00	
1H	4410 000360219		DISK,VALVE	EA	56.00	.0008	1	1	U		0	00	M
1H	4410 000360244		CLAMP,TESTING	EA	38.50	.0008	1	1	U		0	00	M
1H	4410 000360250		SCREW ASSY	AY	26.80	.0000	1	1	U		0	00	M
9G	3460 000360283		BLOCK,LAPPING	EA	46.01	.0250	1	1	U		0	00	
9C	4820 000360444		DISK,VALVE	EA	13.42	.0040	1	1	U		0	00	
2H	4410 000360447		VALVE,SAFETY	EA	2790.00	.0000	1	0					
9C	4820 000360714		DIAPHRAGM,VALVE,FLA	EA	95.68	.0080	1	1	U		0	00	
9C	4820 000361241		SEAT,VALVE	EA	90.40	.0020	1	1	U		0	00	
9G	4820 000361249		DISK,VALVE	EA	110.24	.0070	1	1	U		0	00	
9C	4820 000361252		PUSHROD	EA	16.22	.0070	7	1	U		0	00	
9C	4820 000361253		PUSHROD	EA	18.72	.0090	8	1	U		0	00	
9C	4820 000361256		DIAPHRAGM	EA	16.04	.0170	19	1	U		0	00	
9C	4820 000361257		DIAPHRAGM	EA	31.30	.0460	1	1	U		0	00	
9C	4820 000361269		DISK,VALVE	EA	26.83	.0070	4	1	U		0	00	
9C	4820 000361270		LOADING UNIT	AY	55.12	.0030	1	1	U		0	00	
9C	4820 000361323		CAP ASSEMBLY	EA	13.42	.0400	1	1	U		0	00	
9G	6680 000361359		CHECK,VENT	EA	67.72	.0160	1	1	U		0	00	
9G	6680 000361360		CONTROL METER,FLOW	EA	34.13	.0230	1	1	U		0	00	
9C	4820 000361392		DIAPHRAGM,VALVE,FLA	EA	16.43	.0580	1	1	U		0	00	
9C	4820 000361398		DIAPHRAGM,VALVE,FLA	EA	25.27	.0030	1	1	U		0	00	
9C	4820 000361505		CHAMBER,STEAM	EA	40.98	.0140	1	1	U		0	00	
9C	4820 000361506		BOTTOM,CYLINDER	EA	6.04	.0020	15	1	U		0	00	
9C	4820 000361509		BOTTOM,CYLINDER	EA	11.96	.0040	1	1	U		0	00	
9C	4820 000361510		BOTTOM,CYLINDER	EA	6.09	.0080	3	1	U		0	00	
9C	4820 000361514		BODY,NEEDLE VALVE	EA	36.50	.0100	1	1	U		0	00	
9C	4820 000361516		PISTON,VALVE	AY	25.69	.0030	30	1	U		0	00	
9C	4820 000361517		PISTON	AY	30.47	.0100	1	1	U		0	00	
9C	4820 000361520		PISTON	AY	99.50	.0160	1	1	U		0	00	
9C	4820 000361521		CAP,TOP	EA	127.92	.1160	1	1	U		0	00	
9C	4820 000361523		PISTON	AY	44.41	.0050	1	1	U		0	00	
9C	4820 000361524		ROD,CONNECTING	EA	6.81	.0100	11	1	U		0	00	
9C	4820 000361526		VALVE,NEEDLE	EA	5.51	.0020	63	1	U		0	00	
9C	4820 000361529		DISK,VALVE	EA	31.20	.0020	1	1	U		0	00	
9C	4820 000361530		CAP,TOP	EA	235.04	.0930	1	1	U		0	00	
9C	4820 000361532		DISK	EA	96.72	.0030	1	1	U		0	00	
9C	4820 000361534		DISK,VALVE	EA	151.84	.0120	1	1	U		0	00	
9C	4820 000361536		CHAMBER,DIAPHRAGM	EA	200.72	.0940	1	1	U		0	00	
9C	4820 000361544		SEAT,VALVE	EA	3.70	.0010	3	1	U		0	00	
9C	4820 000361552		PISTON	AY	56.16	.0300	4	1	U		0	00	
9C	4820 000361554		DIAPHRAGM	EA	6.87	.0310	1	1	U		0	00	
9C	4820 000361555		SEAT,SPRING	EA	7.80	.0070	95	1	U		0	00	
9C	4820 000361557		DISK,VALVE	EA	309.20	.0320	1	1	U		0	00	
9C	4820 000361558		DISK,DIAPHRAGM	EA	5.88	.0010	39	1	U		0	00	
9C	4820 000361559		STEM,FLUID VALVE	EA	6.22	.0020	100	1	U		0	00	
9C	4820 000361561		DISK,DIAPHRAGM	EA	80.32	.0230	1	1	U		0	00	
9C	4820 000361562		DIAPHRAGM ASSEMBLY	AY	23.19	.0480	1	1	U		0	00	
9C	4820 000361566		CAP,TOP	EA	238.16	.0980	1	1	U		0	00	
9C	4820 000361575		DIAPHRAGM,VALVE FLA	EA	3.03	.0040	32	1	U		0	00	
9C	4820 000361591		SCREW AND HANDWHEEL	AY	40.77	.1400	1	1	U		0	00	
9C	4820 000361592		CROSSHEAD	EA	17.89	.0020	1	1	U		0	00	
9C	4820 000361593		CAGE,SPRING	EA	7.90	.3500	1	1	U		0	00	
9C	4820 000361596		HOUSING,DIAPHRAGM	EA	221.52	.0070	1	1	U		0	00	
9C	4820 000361610		GUIDE,ROD	EA	3.94	.0030	13	1	U		0	00	
9C	4820 000361649		ROD,CONNECTING	EA	6.12	.0100	81	1	U		0	00	
9C	4820 000361675		SPRING,HELICAL COMP	EA	7.62	.0010	6	1	U		0	00	
9C	4820 000361687		DISK,VALVE	EA	.58	.0100	10	1	U		0	00	
9C	4820 000361702		SEAT,CONTROL VALVE	EA	79.04	.0000	1	0					

SPCC Responsibilities

The organization within the Ships Parts Control Center that has the greatest impact on the Load List process is the Allowance Division. It is this division that has responsibility for preparing new and critical equipments technical overrides for Fleet Issue Load Lists. It also plays a major role in the Tender and Repair Ship Load List process; producing the candidate list, assigning "pre-model" overrides, analyzing the review and SKIM listing produced by the Load List operation, and making "post-model" changes.

The Allowance Division interacts with the Stock Control Division in the preparation of critical equipments overrides. The override candidates are forwarded to Stock Control for review. However, the Allowance Division must approve all changes made by the Stock Control Division.

The Strategic System Support Division of SPCC prepares the technical overrides for the Weapon System Supplement for FBM tender loads.

NAVSUP Responsibilities

The Naval Supply System Command has responsibilities in both the FIRL/FILL and TARSLL areas. NAVSUP must approve the financial statistics associated with both lists prior to publication and distribution of the final outputs. NAVSUP must also approve any technical overrides prepared for augmented support of new and critical equipments.

Other Organization Responsibilities

Numerous other organizations have inputs to the Load List operation. An example of some of these can be obtained by examining the Program Management Plans presented in Chapters V and VI.

II

MOBILE LOGISTIC SUPPORT FORCE DEMAND COLLECTION

In order to prepare an effective Load List that will accurately reflect the required range and depth, it is desireable to introduce actual demand experience into the calculations. (Some loads, however, are produced without using demand.) Demand is introduced by accumulating demand transactions reported by Mobile Logistic Support Force (MLSF) resupply ships, repair ships, tenders, and selected shore activities and then extracting those transactions necessary to produce a Tender and Repair Ship Load List (TARSLL) or a Fleet Issue Requirements List (FIRL).

DEMAND CATEGORIES

Demand transactions are forwarded to the Fleet Material Support Office (FMSO) on a monthly basis. The demand transactions may be classified in one of two categories: Industrial (Category 1) or Fleet Issue (Category 2).

INDUSTRIAL DEMAND

Industrial demand transactions originate from the industrial shops of tenders, repair ships and support detach-

Types of Demand

ments. To be included in this category the demand must be the result of work performed for supported fleet units (e.g., ships, submarines, etc.). The work can be performed either in the industrial shop or on board the supported fleet unit. This type of demand transaction is Category 1 demand and has the Unit Identification Code (UIC) of the serviced ship on the transaction submitted to FMSO.

FLEET ISSUE DEMAND

Fleet Issue demand transactions are resupply requisitions for material placed by customer ships on the MLSF units. This type of demand transaction is Category 2 demand and has the Unit Identification Code (UIC) of the requesting ship in the transaction submitted to FMSO.

TRANSACTION FORMAT

The standard demand transaction reporting format is given below:

Position	Description
1	Record Type (Always 1)
2	Demand Category Code (1 or 2)
3-5	Project Code
6-7	Blank
8-20	National Stock Number, "I" Cog Ordering Number, or Navy Item Control Number

Position	Description
21-22	Blank
23-24	Unit of Issue
25-29	Demand Quantity
30-43	Document Number
30-35	Requesting Ship's UIC
36-39	Julian Date
40-43	Serial Number
44-54	Blank
55-56	Cognizance Symbol
57	Blank
58-62	Demand Reporting Activity UIC
63-65	Blank
66-69	Reporting Date (year and month)
70	Transaction Code (R: issue, G: not in stock, B: not carried)
71-75	Serviced Ship UIC (Required for Category 1 demand) Blank

DEMAND VALIDATION

All demand transactions received by FMSO are subjected to validation criteria. The following data elements are the primary data fields validated.

- Activity Account Number
- Record Type
- Cognizance Symbol (Cog)

- Project Code
- Quantity
- National Item Identification Number (NIIN)
- Federal Supply Group (FSG)
- Demand Category Code
- Reporting Date
- Serviced Ship UIC

The validation rules for the above data elements are as follows:

Validation

Activity Account Number - The reporting activity's Unit Identification Code is matched to a table of valid Activity Account Numbers. The table contains the account numbers of all approved Mobile Logistic Support Force demand reporting activities. If a match is not found, the transaction is rejected and displayed on a review output.

Record Type - Only Record Type 1 transactions are valid. A number other than 1 in the Record Type field will cause a validation error.

Cog - Cognizance Symbol "1Q" items are not included in the MLSF Demand File.

Project Code - If the Project Code field is blank, a code of YY9 is inserted and processing continues.

If the Project Code is not blank, then it must either be ZX9, or all numerics other than 000, or the second position must be either E, K, L, M, N, O, P, V, or Y. A Project Code other than those mentioned will cause the transaction to be rejected.

Quantity - The demand quantity should be numeric and greater than zero. If it is equal to zero or is non-numeric, a quantity of 1 is inserted in the quantity field, a review output is generated, and processing of the transaction continues. Any non-numeric character, other than an X overpunch (reversal), will cause the record to be rejected.

NIIN - Items with an "LF" in the first two positions of the NIIN are rejected from further processing. However, these items are retained on a separate file to be forwarded to NPFC Philadelphia on a monthly basis.

FSG - Items with a Federal Supply Group of "11, 87, 88, or 89" are rejected.

Demand Category Code - Record is by-passed if the demand category is other than "1" or "2".

Reporting Date - If a new demand transaction has a reporting date more than 24 months old, it is rejected

and a review output is generated. If a new demand transaction is post-dated, the program enters the current date and provides a review output.

Serviced Ship UIC - A category "1" demand must reflect the UIC of the serviced ship. If the transaction does not contain a valid UIC, the UIC of the reporter is entered.

Demand transactions that are rejected or require further review are printed on an Error/Review listing for corrective action to be taken, if required. An example of the Error/Review List is shown on the next page.

CANCELLATION RECORDS

Cancelling demand

Each month new demand transactions are checked to determine if they contain a cancellation record. This is determined by an "11" overpunch in column 25 of the quantity field.

When this condition occurs, the file containing the current month's input is searched for a duplicate record (less the "11" overpunch). When a match is found, both transactions are deleted. If a match is not found, the cancellation demand transaction is rejected.

RECORD TYPE / DEMAND CAT / PROJECT CODE / NSN	UNIT OF ISSUE / QUANTITY / REQUEST SHIP UIC / JULIAN DATE / SERIAL NO.	COG	REPORTER UIC	REPORTING DATE / TRANSACTION CODE / SERVICED SHIP	
12ZX951200030523061	EA00001I 62649	F9Q	62649	7705R	62649
12ZX951200001897921	JE000-1 62649	F9Q	62649	7705R	62649
12ZX94R200022701621	EA00000 62649	F9C	62649	7705R	62649
12ZX980100002869081	0C00(11 62649	F9Q	62649	7705R	62649
12ZX951100023465281	WE000-4 62649	F9Q	62649	7705R	62649
11GK540200055611251	SLR0000 0881071094104	9Z	08810	7705B03885	03885
12YY934390020438551	EA0000J 5702071041118	9G	00314	7705R	57020
12YY959350072104951	000019N 3467171323063	9N	00314	7705R	34671
12LE553300062740851	EA00000 0313371254531	F9Z	00651	7705R	03133
12FK058450037072161	EAL3331 050766286W0X9	1 1H	04689	F 7705B04689	05076

EXAMPLE OF ERROR/REVIEW LIST

NIIN UPDATE

Getting the preferred NIIN

Once demand transactions pass the validation criteria, they must be checked to determine if they contain the most preferred NIIN. In addition to the current month's transactions, the MLSF Master Demand File (containing the past two years' historical demand data) and the History Change File (containing manual changes to historical demand records) are also checked for the preferred NIIN. This check is accomplished by matching the NIINs on the records contained in the files just mentioned to the Preferred NIIN File and the Navy Management Data File (NMDF) Addendum File. This latter file cross references old (superceded) NIINs to current NIINs.

Records from the History Change File are matched to the MLSF Master Demand File. If a match is made on NIIN, then either the record on the Master Demand File is deleted or the quantity changed, depending on the type of change. After the update is performed, the NMDF Addendum File is accessed to determine if a NIIN has been changed. If a record from the current month's transaction or a Master Demand File record matches an old NIIN, the NIIN is changed to the new NIIN.

Then, the current month's transactions and the Master Demand File records are matched to the Preferred NIIN File.

If a match is made, the Preferred NIIN is inserted. The Preferred NIIN File also contains a quantity conversion factor if there is a change in the Unit of Issue. Therefore, when a match is made, and the Preferred NIIN is inserted in the demand transaction, the quantity of the demand transaction is adjusted by the conversion factor if applicable.

MLSF MASTER DEMAND FILE UPDATE

Master Demand File update

After completion of the Preferred NIIN update of the three input files, the next step is to update the MLSF Master Demand File. All input demand transactions (i.e., those contained on the Current Month's Demand File, Change History File, and the MLSF Master Demand File) are matched to the Load List Stock Number File, sometimes referred to as the NMDF Load List File. This file contains all NIINs that have Navy interest registered at the Defense Logistic Support Center (DLSC). For each NIIN in the file, there is also management data necessary for Load List development and demand maintenance.

One such data element is the Unit of Issue. If the demand transaction matches the Load List Stock Number File on NIIN, then the Unit of Issue (U/I) on the Stock Number File is compared to the U/I on the demand transaction. Actually, the Load List Stock Number File contains both the new U/I and the old U/I. If the U/I of the demand transaction matches either one, a valid match is made. However, if the match is on the old U/I, the U/I of the transaction is changed to the new U/I and the quantity is adjusted.

If the U/I does not match either Stock Number File U/I, then a U/I conversion is attempted by matching it to a U/I conversion factor in a System Constant Area (SCA) table. If this also fails, the demand transaction is not used to update the MLSF Master Demand File and is, instead, output on a review list for correction.

If a NIIN on a demand transaction is not matched to a NIIN in the Stock Number File, then the transaction is placed in an Unmatched Demand History File. Each item in this file is reviewed and any item that has received more than a specified number of demands during a 24 month period is printed for review by FMSO personnel. The number of demands required is determined by FMSO and is input to the program via a parameter card.

In addition, for those items meeting the above criterion, a card is prepared and submitted to DLSC for NIIN interrogations. In this situation, the demand transaction is uniquely identified to prevent subsequent interrogations from being submitted.

Unmatched demand

Each month, the Unmatched Demand History File transactions are checked against the NIINs in the Stock Number File. If a match is made, the transaction is migrated to the MLSF Master Demand File.

DEMAND QUANTITY VALIDATION

The demand transactions remaining in the current month's demand file are validated with regard to a potential excessive demand quantity. This is accomplished using the procedures described in this section.

Checking the quantity

If a reporting activity has two or more demands in the MLSF Master Demand File for a specific NIIN contained on a new demand transaction, an Average Requisition Quantity (ARQ) is computed. The ARQ is

$$\text{ARQ} = \frac{\text{Sum of all Demand Quantities on Demand History}}{\text{Sum of Frequencies (e.g., number of Demands on Demand History)}}$$

If the ARQ is greater than 20, then the ARQ is multiplied by a factor set via a parameter card. The factor can be from 1 to 99. Therefore, the acceptable demand quantity becomes:

Upper Limit = ARQ x Parameter Factor

The new demand quantity is compared to the Upper Limit. If the quantity is equal to or less than the Upper Limit, the new demand quantity is unchanged and the MLSF Master Demand File is updated with the new demand quantity. If the quantity is greater than the upper limit,

the demand quantity is changed to the upper limit and the MLSF Master Demand File is updated with the changed demand quantity.

If there are less than two demands in the MLSF Master Demand File for the particular reporter and NIIN, then the new demand quantity is compared to 500. If it is greater than 500 and the Item Replacement Price is greater than $1.00 and the extended price is greater than $1000 (i.e., Quantity x Replacement Price > $1000), the new demand transaction is not added to the MLSF Master Demand File. Instead, the transaction is output on a review list for resolution.

Further demand checks

If a new demand quantity fails the $1000 extended price test but the quantity is greater than 5000, the demand transaction will not update the MLSF Master Demand File. It will also be output on a review list for resolution.

Any demand quantities not meeting the above stated conditions will be updated to the MLSF Master Demand File. In addition, the oldest demand segment (25th month) is dropped from the file when a new monthly segment is entered.

DEMAND EXTRACTION FROM THE MLSF MASTER DEMAND FILE

After the MLSF Master Demand File has been updated with the current month's demand transactions, the final step in the operation is to extract the demand from the file for those activities contained on the Load List Extract Requests File. In addition to these two files, the Load List Navy Management Data File is also accessed in order to obtain management data concerning the NIINs extracted. At this time, there is also an override file that is used to include or exclude particular NIINs' demands from the Load List computation. Also, items reflecting specific Cognizance Symbols (up to a maximum of 18) may be excluded from the demand extraction via a parameter card input.

Extracting the demand

Demand is extracted from the MLSF Master Demand File for NIINs associated with a particular requestor/reporter contained in the Load List Extract Request File. Demand can be extracted by reporter, requestor, or requestor within reporter. The demand is extracted by quarters and summarized by Load Activity Code. More specifically, the demand is summarized into eight quarterly increments of demand quantity and frequency. Concurrent with the extraction of demand from the MLSF Master Demand File, management data for the particular NIIN is extracted from the Load List NMDF (e.g., Unit Price, Material Control Code, SMIC, Item Name, etc.).

The output of this operation is the Load List MLSF Demand Extraction File. This file is used as an input for projecting load list material requirements.

III

LOAD LIST OVERRIDES

Under some conditions, the range and depth decisions made by the UICP Load List operations based on experienced/predicted demand can be overridden. Items can be added or deleted from the Load List range and modifications can be made to the depth of particular items. Of special interest are the two conditions requiring Inventory Control Point Technical Override actions. These two conditions are the support of newly deployed equipments and the support of critical equipments.

Overrides may be made to both the FIRL/FILL and the TARSLL.

TYPES OF OVERRIDES

There are four types of Technical Overrides. They are:

Mandatory Quantity Override
Maximum Quantity Override
Minimum Quantity Override
Exclusion (Deletion) Override

Mandatory quantity override

If an item has been coded with a Mandatory Quantity Override, it must be included in the Load List range and its depth will be the override quantity. A Mandatory Quantity Override item may or may not have a history of demand and, in fact, may

have been included on the Load List without the override. However, the use of the override ensures that the item will be on the load and at the desired quantity.

Maximum quantity override

A Maximum Quantity Override is used to limit the depth of an item. The item must first have a demand-based depth computed by the Load List operation. If the computed depth is less than the override quantity, the computed depth is used as the Load List quantity. If the computed depth is greater than the override quantity, the override quantity is used as the Load List quantity.

Minimum quantity override

An item that has been assigned a Minimum Quantity Override must be included in the Load List range and must have a depth at least as great as the override quantity. If the Load List operation does not include the item in the Load List range or computes a demand-based depth that is less than the override quantity, these computations will be overridden and the item's depth will be the override quantity. If the demand-based depth is greater than the override quantity, the demand-based depth will be the Load List quantity.

Exclusion override

An Exclusion Override will prevent an item from being included on the Load List regardless of its demand.

SOURCES OF FIRL/FILL OVERRIDES

FIRL/FILL Technical Overrides may enter UICP processing at several different points in the operation. The principal source of the overrides will be the ICP although the primary impetus for an override may come from Type Commanders, Hardware System Commands, or the Chief of Naval Operations. Overrides are authorized by CNO.

NEW EQUIPMENTS OVERRIDES

New equipments overrides

A newly deployed equipment must be provided resupply support even though it has no experienced demand. A Mandatory or Minimum Quantity Override can be used in this case to ensure some degree of support until sufficient demand is experienced to compute a demand-based depth.

For the FIRL, new equipment override nominations are made by a Fleet Commander in Chief. The nominations must be approved by CNO (OP-04) and are then forwarded to the Ships Parts Control Center (SPCC) with guidance regarding the degree of support to be provided.

At SPCC, the new equipment candidates are investigated by the Allowance Division so that demand for the item can be estimated. UICP files data may be utilized in this analysis

The Master Data File records for similar items that have a demand history may be examined and used to estimate the candidate's expected demand and override quantity. The candidate item's population and Best Replacement Factor (BRF) may be examined and used to estimate the item's demand and necessary override quantity.

In general, a Minimum Quantity (FIRL quantity) override will be used to place one unit on each FILL of the FIRL being developed. Of course, if there is a Minimum Replacement Unit for the item, the override quantity will be in multiples of the number of FILLs times the Minimum Replacement Unit.

FIRL/FILL CRITICAL EQUIPMENTS OVERRIDES

This category of override is used to provide adequate support for equipments that have been classified critical in terms of operational readiness. Equipments designated critical are to be given special attention. Critical items are not items included on individual COSALs.

Critical equipments overrides

A critical equipment override will be a Minimum Quantity Override. In our analysis of the problem, we are concerned with determining the depth necessary to solve the problem. If the experienced demand causes a larger quantity to be computed, this larger value will be the Load List quantity.

FMSO provides the data for the analysis of critical equipments via the CASREPT and fleet usage (3M) reports.

"Top 40" list

Prior to the preparation of the two editions of the FIRL/FILL (Pacific and Atlantic), SPCC is given the responsibility of providing FMSO with override inputs related to a list of CNO approved critical equipments. This list of critical equipments is more commonly called the "Top 40" List. FMSO selects these critical equipments based on an analysis of CASREPTs and performs a preliminary screening to remove non-Load List type items; such as furniture.

Allowance Division

SPCC's Allowance Division identifies the Allowance Parts Lists associated with these critical equipments. The APL numbers are forwarded to FMSO where they are used to extract those NIINs that have experienced three or more CASREPTs or a usage of three or more (from 3M data base) over the previous year. The extracted NIINs become override candidates subject to review by the Allowance Division.

Stock Control Division

The override candidates are forwarded to the Stock Control Division where they are reviewed and the decision is made regarding further pruning of the candidate list. Any deletion or replacement recommendations made by Stock Control must be annotated with an explanation for the decision. Stock Control may also assign some items the designation FIRL Only which serves to reduce the total quantity required.

The Allowance Division reviews Stock Control's suggested changes to the override candidate list. A Stock Control deletion recommendation may be overruled should a technical investigation show the item to be critical to the operational readiness of a specific equipment.

The Allowance Division supplies FMSO with a listing of the FIRL/FILL critical equipments override items. The data are provided on cards in the format required of the FIRL/FILL operation. The cards are converted to magnetic tape and than merged with the regular override file. The regular override file is a record of overrrides as established by Type Commanders, Hardware System Commands, or the Chief of Naval Operations.

FMSO is also given a breakdown by SPCC as to the override candidates that were selected for FIRL Only and their total dollar value, the candidates that were selected for FIRL/FILL and their total dollar value, and the candidates that were not selected and the reasons for their non-selection.

TARSLL OVERRIDES

There are two stages in the TARSLL process where overrides may be entered. The first stage is at the time of the screening of the initial candidate listing. The overrides resulting from this screening are sometimes called "pre-model" overrides. The second stage occurs after the depth

computations have been made and the overrides are based on an examination of the various review and SKIM listings. These overrides are actually quantity adjustments (adds, deletes, changes). The various listings will be discussed in more detail in the chapter on TARSLL preparation.

Getting the candidates

Once the designated hull mix has been given SPCC's Allowance Division and the Weapon Systems File has been accessed to obtain the candidate listing, the screening process takes place. Allowance Division personnel compare SPCC-managed candidates to their override files and matching items are assigned overrides. The override files are based on messages or letters from NAVSUP or TYCOMs or on OPNAV designated criteria.

As will be discussed in detail in a later chapter, FMSO extracts the demand data associated with the candidate items, performs some degree of quality control on the data, and the required data are input to the TARSLL computation procedures.

Once a Load List has been computed that meets the specified goals, a series of listings are prepared. Upon receipt, FMSO forwards these listings to SPCC for review.

These listings are explained in Chapter IV, but we can summarize them as follows:

Listing Identifier	Purpose
RC1L	A listing of the Load list if it were to be unchanged.
MA1L	A listing of all candidates with the new and old quantities, Override Code, override quantity, population data, and a Review Code. The Review Code compares the two Load List quantities, identifies missing data, and flags excessive extended price, quantity, or demand forecast.
LD1L	Quantity SKIM. Lists item quantities in ascending order
LE1L	Demand Frequency SKIM. Lists item demand frequencies in ascending order.
LF1L	Price SKIM. Lists item extended prices in ascending order.

Listing Identifier	Purpose
LG1L	National Stock Number List. Listing of items in NSN sequence.

These listings are reviewed by Allowance Division personnel. The Price SKIM is examined, beginning with the highest priced items, in order to minimize the cost of the Load List by reducing the quantities of these items if they are not justified by the demand. The Quantity SKIM is compared to the Demand Frequency SKIM to ensure that the quantity is justified by the demand.

SKIM listings

The preliminary Load List is also compared against additional override files to determine if further exclusions or additions are required.

FMSO also reviews all of these listings for possible deletions and erroneous or missing data in the same manner as SPCC's Allowance Division. FMSO's review is primarily concerned with the retail Cogs although, should questions arise relative to SPCC Cogs, the responsible Allowance Division technician is contacted for resolution.

The preliminary Load List is updated through a files maintenance procedure which incorporates the "post-model" changes and data corrections.

IV

ICP EQUIPMENT/COMPONENT POPULATION AND INDEX DATA

There are two instances when the ICP files must be accessed to obtain information necessary to the Load List operations. The first, and major, situation is in the development of the candidate list for a tender or repair ship Load List. The second instance occurs when, in the absence of demand data, it is necessary to extract data regarding an item's installed population and its failure rates.

The ICP files that contain the necessary information are the Weapon Systems File (WSF), the Master Data File (MDF), and the Program Support Interest File (PSI).

We will discuss each of these files and describe the data obtained from them.

WEAPON SYSTEMS FILE

The WSF, as its name implies, is a file of information about the weapon systems being managed by a particular ICP. It contains data releated to end use weapons (ships/aircraft), systems, subsystems, equipments, components, sub-components, and parts. Its records also include the interrelationships between these various elements. The interrelations are identified by means of the Repairable Identification Code (RIC) and the Application Code (AC).

RIC The RIC is a unique identifier describing a repairable item that has lower level items related to it.

Application Code The Application Code identifies a higher level assembly to which an item is related. It will be the RIC of that higher level assembly. Since an item can be used in a number of higher assemblies, its record may contain more than one AC.

WSF structure The WSF is structured in three levels, designated A, B, and C. The items contained in Level A are specific end user weapons; for example, a ship or an aircraft. Each of these end use weapons has an associated RIC which is the Unit Identification Code of the ship or aircraft and the file can be accessed using it. If only the Ship Type and Hull Number is known, a file interrogation can be made using this information and the UIC can be obtained.

The Level A record for each end use weapon contains the RICs of lower level systems and components, as well as identifiers for Allowance Parts Lists.

Level B of the WSF has the records for systems and equipments and are related to the end use weapon in Level A and other entries in Levels B and C.

Level C records are those of components, equipments, Allowance Parts Lists, and Allowance Equipage Lists. Each

of these records contains a breakdown of the individual parts that make up the component, equipment, APL, or AEL.

EXTRACTING LOAD LIST POPULATION DATA FROM THE WSF

As we will discuss in a later chapter, one of the first requirements before a tender or repair ship Load List (TARSLL) can be constructed is the specification, by the Type Commander, of the hull mix to be supported by the load. By hull mix, we mean the specific ships, designated by Ship Type and Hull Number and the Unit Identification Code (UIC), that the TARSLL will support.

Hull mix

From the previous discussion of the WSF structure and access keys, we see that, once the hull mix has been defined, we can enter Level A with each UIC and extract a listing of all the APLs associated with the ships to be supported.

Once the APLs are known, the individual item records can be obtained from Level C. The records extracted will be in NIIN sequence for each APL and contain the following information:

- the designator of the agency with technical cognizance for the item.

- an average Military Essentiality Classification

- the maximum Military Essentiality Classification

- for FBM: the total quantity of the item on the APL

- for non-FBM: the total quantity designated vital and the total quantity designated non-vital on this APL.

The reason for including the Military Essentiality information is because it may be used in the depth cal-cultations for the TARSLL.

EXTRACTING LOAD LIST DATA FROM OTHER FILES

Accessing the MDF and PSI

Once this basic information has been extracted, the Program Support Interest File and the Master Data File are accessed for additional information. The MDF contains a wealth of data about each item managed by SPCC. For a discussion of the contents of this file the reader is referred to the Basic Inventory Manager's Manual. The PSI contains similar information but for items managed by other Inventory Managers.

The information extracted from the MDF or PSI includes:

DEN	Data Element Description
C042	Federal Supply Classification
C004	Item Name
C003	Supply Management Cog
C003A	Material Control Code
C005	Unit of Issue
C003B	Special Material Identification Code
C012	Source Code
C017	Security Classification Code
C027	Type of Storage Space Code
D015	Special Material Content Code
B053	Unit Price
C024A	Volume of Item (Net Cube)
F027	Best Replacement Factor
C023A	Net Weight
D013A	Replacement Maintenance Code
D013B	Repair Maintenance Code
C007	Minimum Replacement Quantity
E007	Allowance Equipage List Quantity

After the data is extracted from the MDF and PSI for all NIINs for all APLs, the records for the same NIINs are combined and the quantities are accumulated. The accumulated quantities (i.e., the total number of times the NIIN is installed in an application for all applications) give us the required population information.

LOAD LIST INDEX DATA

When Level C of the Weapon Systems File is being accessed, some additional information is extracted for preparing load list indexes. Among the information is:

- the APL nomenclature; a group of words or symbols that describe the APL
- for FBM Load Lists: the APL quantity for each hull being supported.

This additional data permits the printing of a Load List Index. The index comes in two sections, A and B. Section B will be printed for FBM Load Lists only. An example of Section A is shown on the next page. As can be seen, it is a listing in APL nomenclature sequence, relating the nomenclature to the APL ID (its RIC).

Load List Index

Section B of the index contains a bit more information as can be seen on page 4-8. Here the listing is in RIC sequence and for each RIC gives its nomenclature, Logistics Support Status Code (showing type, degree, and method of support), and the APL application to each hull.

APL NOMENCLATURE	ID NUMBER
EXCITER-STC 352000AL117A1	420030298
EXHAUST SYSTEM GROUP	950072957
EXTRACTOR GBG CHRL 200LBS HR AC 44	432390004
FAN AC 12IN BRKT NOSCW 115V	400700001
FAN AC 8.0IN CELG STNRT 115V 1570RP	400220001
FAN AC 12.0IN BRKT NOSCW 115V	400330006
FAN AC 12.0IN BRKT NOSCW 115V 1240/1550RP	400490001
FAN CTFGL 500C	400340001
FAN CTFGL UP BLST MTR	400030012
FAN CTFGL SZ CC1A4A5CHMNS 1000C	400060438
FAN CTFGL SZ CC1-2A4N6CCHMNS 500C	400060284
FAN CTFGL SZ CC2A4N5CCHMNS 2500C	400060285
FAN CTFGL SZ CC4A4N6CHNS 6000C	400060294
FAN CTFGL SZ CC8A4N6CHMNS 6000CFM	400060277
FAN CTFGL SZ C1-2A4N5CCHMNS 500C	400130124
FAN CTFGL SZ C4A4N5CHMNS 4000C	400130110
FAN CTFGL SZ 2RE CCHMNS 75C	400060624
FAN CTFGL PRTL SZ 03-6T 750C	400060001
FAN CTFGL GLD EXH	400020181
FAN CTFGL GLD EXH 150CFM TOP HORZ DSCHG MTR	400120002
FAN CTFGL GLD EXH 350CFM TOP HORZ DSCHG MTR	400020008
FAN CTFGL GLD EXH 55CFM	400120014
FAN TBXL SZ L1A1N5 1000C	400160030
FAN TBXL SZ L1-2A1N5 500C	400090114
FAN VNXL	400090164
FAN VNXL	400090166
FAN VNXL	400090307
FAN VNXL SZ A1 1-2A4N5 1500C	400060247
FAN VNXL SZ A1 1-2A4N6 1500C	400090302
FAN VNXL SZ A1A4N5 1000C	400060253
FAN VNXL SZ A1A4N6 1000C	400060570
FAN VNXL SZ A1A4N6 1000C	400560189
FAN VNXL SZ A1-2A4N6 500C	400060326
FAN VNXL SZ A1-2A4N6 500C	400060679
FAN VNXL SZ A1-2A4N6 500C	400560198
FAN VNXL SZ A1-4A4N5 250C	400090020
FAN VNXL SZ A1-4A4N6	400060626
FAN VNXL SZ A1-4A4N6 250C	400090335
FAN VNXL SZ A10A4N5 10000C	400060307
FAN VNXL SZ A10A4N6 10000C	400060567
FAN VNXL SZ A10A4N6 10000C	400560202
FAN VNXL SZ A12A4N6 12000CF	400560204
FAN VNXL SZ A16A4N6 16000C	400060566
FAN VNXL SZ A16A4N6 16000C	400560196
FAN VNXL SZ A2A4N6 2000C	400060543
FAN VNXL SZ A2A4N6 2000C	400090200
FAN VNXL SZ A20A4N6 20000C	400060581
FAN VNXL SZ A25A4N6 25000C	400090310
FAN VNXL SZ A28A4N6 28000C	400560201
FAN VNXL SZ A3A4N5 3000C	400090136
FAN VNXL SZ A3A4N6 3000C	400060472
FAN VNXL SZ A3A4N6 3000C	400560192
FAN VNXL SZ A4 1-2A4N6 4500C	400060319
FAN VNXL SZ A4A4N6 4000C	400560191
FAN VNXL SZ A5A4N5 5000C	400060283
FAN VNXL SZ A5A4N6 5000C	400060579
FAN VNXL SZ A6A4N5 6000C	400060252
FAN VNXL SZ A6A4N6 6000C	400090206
FAN VNXL SZ L1-2A1N5 500C	400560205
FAN VNXL SZ XA2A4N6 2000C	400090270
FAN VNXL SZ 01-2U1X5 500C	400390003
FAN VNXL PRTL SZ 01-2A1X5 500C	400090105
FAN VNXL PRTL SZ 01-2A1X5 500C	400130047
FAN VNXL PRTL SZ 01-2A1X5 500C	400130084
FAN VNXL PRTL SZ 01-2D1X5 500C	400300001
FAN VNXL FRO STN TOVN 19300C	057800081
FAN-CTFLG	400010003
FAN-VNXL SZ A16A4N6 16000C	400090236
FAUCET SGL .500 IPS BRS CRS HNUL	670010012
FAUCET SGL .750 IPS BRS CRS HNUL	670010016
FAUCET SGL 0.500 IPS BRZ	679993041
FILTER ACNG	489980159
FILTER ACNG MOL 12AF STL	489980003
FILTER AIR MOL 2306	480450001
FILTER AIR CFM CAP MOL 7-1031	489980218
FILTER AIR 30CFM CAP MOL 5321436A1	480240007
FILTER AIR CNDN MOL 10AF STL	489980001
FILTER AIR CNDN MOL 13AF ALUM	489980108
FILTER AIR CNDN MOL 14AF ALUM	489980110
FILTER AIR CNDN MOL 15AF STL	489980006
FILTER AIR CNDN MOL 16AF STL	489980007
FILTER AIR CNDN MOL 9804	489980015
FILTER ASSY SML LGT	239990097
FILTER FD PRESS MOL A3848 84V FULFLO	480050015
FILTER FD PRESS MOL BK4 1-4	480050092
FILTER FD PRESS MOL DK-6N	480010037
FILTER FD PRESS MOL D-1463	480110020
FILTER FD PRESS MOL D173-3U	480110328
FILTER FD PRESS MOL EGF-3	480060142
FILTER FD PRESS MOL G	480060032

APL NOMENCLATURE	ID NUMBER
EXHAUST SYSTEM GROUP	950072736
FAIRLEAD SHEAVES INHAUL X OUTHAUL BOW RAMP	859990232
FAN AC 8.0IN CELG STNRT 115V 1550RP	401000002
FAN AC 8.5IN CELG STNRT 115V	400490006
FAN AC 12.0IN BRKT NOSCG 115V 1500RP	400540001
FAN AC 12.0IN BRKT NOSCG 115V 1500/1200RP	400220002
FAN CTFGL 2600C	400310002
FAN CTFGL SZ 03-6T 750C	400060433
FAN CTFGL SZ CC1-2A4N5CHMNS 500C	400060274
FAN CTFGL SZ CC1-4A4N6CHMNS 850C	400060282
FAN CTFGL SZ CC2A4N6CHMNS 2000C	400060434
FAN CTFGL SZ CC8A4N6CCHMNS 8000CFM	400060264
FAN CTFGL SZ C1-2A4N5CHMNS 500C	400130017
FAN CTFGL SZ C2A4N5CHMNS 2000C	400130102
FAN CTFGL SZ 2 RECCHUB 54C	400060739
FAN CTFGL SZ 3 1-2RE 50C	400060646
FAN CTFGL GLD EXH	400020180
FAN CTFGL GLD EXH 10CFM UP BLST DSCHG MTR	400060417
FAN CTFGL GLD EXH 250CFM BTM HORZ DSCHG MTR	400020120
FAN CTFGL GLD EXH 200CFM BTM HORZ DSCHG MTR DR	400060416
FAN DC 8.0IN BRKT NOSCG 24V	400340010
FAN TBXL SZ L1-2A1N5 500C	400060404
FAN VNXL	400090163
FAN VNXL	400090165
FAN VNXL	400090167
FAN VNXL SZ A2A4N5 2000C	400060251
FAN VNXL SZ A1 1-2A4N6 1500C	400060571
FAN VNXL SZ A1 1-2A4N6 1500C	400560186
FAN VNXL SZ A1A4N6 1000C	400060424
FAN VNXL SZ A1A4N6 1000C	400090240
FAN VNXL SZ A1-2A4N5 500C	400060250
FAN VNXL SZ A1-2A4N6 500C	400060627
FAN VNXL SZ A1-2A4N6 500C	400090301
FAN VNXL SZ A1-4A4N5 250C	400060312
FAN VNXL SZ A1-4A4N5 250C	400090118
FAN VNXL SZ A1-4A4N6 250C	400060575
FAN VNXL SZ A1-4A4N6 250C	400560194
FAN VNXL SZ A10A4N6 10000C	400060426
FAN VNXL SZ A10A4N6 10000C	400090213
FAN VNXL SZ A12A4N6 12000C	400090233
FAN VNXL SZ A16A4N5 16000C	400090285
FAN VNXL SZ A16A4N6 16000C	400160138
FAN VNXL SZ A2A4N6 2000C	400060271
FAN VNXL SZ A2A4N6 2000C	400060725
FAN VNXL SZ A2A4N6 2000C	400560190
FAN VNXL SZ A20A4N6 20000C	400560203
FAN VNXL SZ A25A4N6 25000C	400560200
FAN VNXL SZ A3A4N5 3000C	400060112
FAN VNXL SZ A3A4N5 3000C	400090226
FAN VNXL SZ A3A4N6 3000C	400060573
FAN VNXL SZ A30A4N6 30000C	400060589
FAN VNXL SZ A4A4N6 4000C	400060606
FAN VNXL SZ A4-1-2A4N6 4500C	400090258
FAN VNXL SZ A5A4N5 5000C	400090238
FAN VNXL SZ A5A4N6 5000C	400560184
FAN VNXL SZ A6A4N6 6000C	400060270
FAN VNXL SZ A6A4N6 6000C	400560158
FAN VNXL SZ XA1-2A4N6 500C	400090265
FAN VNXL SZ X-A3A4N6	400090244
FAN VNXL SZA1 1-2A4N6 1500C	400060545
FAN VNXL PRTL SZ 01-2A1X5 500C	400130001
FAN VNXL PRTL SZ 01-2A1X5 500C	400130082
FAN VNXL PRTL SZ 01-2A1X5 500C	400390002
FAN VNXL FRO STN TOVN 3000C	057120018
FAN VNXL FRO STN TOVN 31700C	057960029
FAN-TBXL SZ A30A4N6 300000C	400560199
FAN-VNXL SZ A20A4N6 200000C	400090239
FAUCET SGL .500 IPS BRS CRS HNOL SCBSG	670010017
FAUCET SGL 0.500 IPS BRZ	670240001
FAUCET SGL 0.750 IPS BRZ	670240007
FILTER ACNG MOL 12 AF ALUM	489980124
FILTER ACNG MOL 14AF STL	489980005
FILTER AIR CFM CAP MOL 7-1030	489980214
FILTER AIR 6CFM CAP MOL 5321972A1	480200006
FILTER AIR CNDN	489980102
FILTER AIR CNDN MOL 11AF STL	489980002
FILTER AIR CNDN MOL 13AF STL	489980004
FILTER AIR CNDN MOL 15AF ALUM	489980113
FILTER AIR CNDN MOL 16AF ALUM	489980012
FILTER AIR CNDN MOL 9802	489980095
FILTER AIR ELCTSTC 28-9171-2	480790036
FILTER DC PWR	619540001
FILTER FD PRESS MOL BFS-6-2-V-50 1 1-2	480030117
FILTER FD PRESS MOL B-109-6	480090006
FILTER FD PRESS MOL DS	480060243
FILTER FD PRESS MOL D1223 003 SPCG	480110014
FILTER FD PRESS MOL D3716760 DUPLEX	480020116
FILTER FD PRESS MOL F30883	480140000
FILTER FD PRESS MOL G	480060201

ID NUMBER	APL NOMENCLATURE	LSSC NEC	616	617	619	620	622	625	627	632	633	634	635	636
			SUPPORTED POPULATION PER SSBN											
882301422	VALVE B 1.00IPS 100PSI SBU BRZ						X	X	X	X			X	
882301422	VALVE B 1.00IPS 100PSI SBU BRZ	AA					X	X	X	X			X	
882301423	VALVE B 1.50IPS 100PSI SBU BRZ						X	X	X	X			X	
882301423	VALVE B 1.50IPS 100PSI SBU BRZ	AA					X	X	X	X			X	
882301424	VALVE B ANL .75IPS 3000PSI SBU BRZ					X								X
882301424	VALVE B ANL .75IPS 3000PSI SBU BRZ	AA				X								X
882301428	VALVE B SPCL 10.00IN FLGE STL													X
882301428	VALVE B SPCL 10.00IN FLGE STL	AA												X
882301429	VALVE B 1.50IPS 4500PSI BTWLD SSTL					X								X
882301429	VALVE B 1.50IPS 4500PSI BTWLD SSTL	AA				X								X
882301432	VALVE B 1.50IPS 4500PSI BTWLD CRS					X								X
882301432	VALVE B 1.50IPS 4500PSI BTWLD CRS	AA				X								X
882301433	VALVE B .12IPS 1000PSI SBU BRZ					X								X
882301433	VALVE B .12IPS 1000PSI SBU BRZ	AA				X								X
882301434	VALVE B ANL 1.00IPS 3000PSI SBU BRZ					X								X
882301434	VALVE B ANL 1.00IPS 3000PSI SBU BRZ	AA				X								X
882301435	VALVE B .50IPS 1000PSI SBU BRZ					X								X
882301435	VALVE B .50IPS 1000PSI SBU BRZ	AA				X								X
882301436	VALVE B .25IPS 1000PSI SBU BRZ					X								X
882301436	VALVE B .25IPS 1000PSI SBU BRZ	AA				X								X
882301437	VALVE B .75IPS 1000PSI SBU SSTL					X			X					X
882301437	VALVE B .75IPS 1000PSI SBU SSTL	AA				X			X					X
882301438	VALVE B .25IPS 1000PSI SBU SSTL					X								X
882301438	VALVE B .25IPS 1000PSI SBU SSTL	AA				X								X
882301442	VALVE B 3WAY 1.50IPS 3000PSI SBU BRZ					X				X				X
882301442	VALVE B 3WAY 1.50IPS 3000PSI SBU BRZ	AA				X				X				X
882301443	VALVE B 3WAY .25IPS 3000PSI SBU BRZ					X								X
882301443	VALVE B 3WAY .25IPS 3000PSI SBU BRZ	AA				X								X
882301446	VALVE B .25IPS 4500PSI SBU SSTL					X								X
882301446	VALVE B .25IPS 4500PSI SBU SSTL	AA				X								X
882301447	VALVE B 1.50IPS 4500PSI SWLDG SSTL					X								X
882301447	VALVE B 1.50IPS 4500PSI SWLDG SSTL	AA				X								X
882301448	VALVE B 1.500IPS 4500PSI SBU SSTL					X								X
882301448	VALVE B 1.500IPS 4500PSI SBU SSTL	AA				X								X
882301450	VALVE B .50IPS 4500PSI SBU SSTL					X								X
882301450	VALVE B .50IPS 4500PSI SBU SSTL	AA				X								X
882301451	VALVE B 2.50IPS 4500PSI SBU SSTL					X								X
882301451	VALVE B 2.50IPS 4500PSI SBU SSTL	AA				X								X
882301452	VALVE B 2.00IPS 4500PSI SBU SSTL					X								X
882301452	VALVE B 2.00IPS 4500PSI SBU SSTL	AA				X								X
882301453	VALVE B 1.50IPS 4500PSI SBU SSTL					X							X	X
882301453	VALVE B 1.50IPS 4500PSI SBU SSTL	AA				X							X	X
882301454	VALVE B 1.00IPS 4500PSI SBU SSTL					X								X
882301454	VALVE B 1.00IPS 4500PSI SBU SSTL	AA				X								X
882301455	VALVE B .75IPS 4500PSI SBU SSTL					X								X
882301455	VALVE B .75IPS 4500PSI SBU SSTL	AA				X								X
882301456	VALVE B .50IPS 4500PSI SBU SSTL					X							X	X
882301456	VALVE B .50IPS 4500PSI SBU SSTL	AA				X							X	X
882301457	VALVE B .25IPS 4500PSI SBU SSTL					X			X					X
882301457	VALVE B .25IPS 4500PSI SBU SSTL	AA				X			X					X
882301458	VALVE B .75IPS 1000PSI SBU SSTL					X								X
882301458	VALVE B .75IPS 1000PSI SBU SSTL	AA				X								X
882301459	VALVE B .25IPS 1000PSI SBU SSTL					X								X
882301459	VALVE B .25IPS 1000PSI SBU SSTL	AA				X								X
882301460	VALVE B 1.00IPS 1000PSI SBU SSTL					X								X
882301460	VALVE B 1.00IPS 1000PSI SBU SSTL	AA				X								X
882301461	VALVE B .50IPS 1000PSI SBU SSTL					X								X
882301461	VALVE B .50IPS 1000PSI SBU SSTL	AA				X								X
882301462	VALVE B 2.50IPS 1000PSI SBU BRZ					X								X
882301462	VALVE B 2.50IPS 1000PSI SBU BRZ	AA				X								X
882301464	VALVE B 1.50IPS 1000PSI SBU BRS					X								X
882301464	VALVE B 1.50IPS 1000PSI SBU BRS	AA				X								X
882301465	VALVE B 1.00IPS 1000PSI SBU BRZ					X								X
882301465	VALVE B 1.00IPS 1000PSI SBU BRZ	AA				X								X
882301466	VALVE B .50IPS 1000PSI SBU BRZ					X								X
882301466	VALVE B .50IPS 1000PSI SBU BRZ	AA				X								X
882301467	VALVE B .12IPS 1000PSI SBU BRZ					X								X
882301467	VALVE B .12IPS 1000PSI SBU BRZ	AA				X								X
882301468	VALVE B 3WAY .50IPS 3000PSI SBU BRZ					X								X
882301468	VALVE B 3WAY .50IPS 3000PSI SBU BRZ	AA				X								X
882301469	VALVE B SPCL 3.00IPS 700PSI FLGE STL					X								
882301469	VALVE B SPCL 3.00IPS 700PSI FLGE STL	AA				X								
882301471	VALVE B ANL 2.00IPS 5000PSI BTWLDUN X BTW							X	X	X			X	
882301471	VALVE B ANL 2.00IPS 5000PSI BTWLDUN X BTW	AA						X	X	X			X	
882301472	VALVE B .75IPS 4500PSI SBU SSTL					X								X
882301472	VALVE B .75IPS 4500PSI SBU SSTL	AA				X								X
882301479	VALVE B 1.50IPS 700PSI FLGE MON							X	X					
882301479	VALVE B 1.50IPS 700PSI FLGE MON	AA						X	X					
882301499	VALVE B .37IPS 1000PSI SBU BRS					X								X
882301499	VALVE B .37IPS 1000PSI SBU BRS	AA				X								X
882301505	VALVE B ANL 1.00IPS 4500PSI SWLDG MON													X
882301505	VALVE B ANL 1.00IPS 4500PSI SWLDG MON	AA												X
882301506	VALVE B 1.00IPS SBU X SWLDG COPNI													X
882301506	VALVE B 1.00IPS SBU X SWLDG COPNI	AA												X
882301507	VALVE B 1.00IPS SBU COPNI													X
882301507	VALVE B 1.00IPS SBU COPNI	AA												X
882301508	VALVE B 2.00IPS 6000PSI BTWLD SSTL								X	X			X	
882301508	VALVE B 2.00IPS 6000PSI BTWLD SSTL	AA							X	X			X	
882301511	VALVE B 3.00IPS 700PSI FLGE COPNI								X	X			X	
882301511	VALVE B 3.00IPS 700PSI FLGE COPNI	AA							X	X			X	

V

FLEET ISSUE REQUIREMENTS LIST

As we discussed in the Introduction, the Fleet Issue Requirements List (FIRL) for a particular fleet is comprised of the Fleet Issue Load Lists (FILLs) associated with that fleet plus any FIRL Only material. In this chapter, we will examine the Load List operations concerned with constructing a FIRL/FILL. A FILL is that material that is placed on board a Combat Store Ship (AFS) or at a designated shore base.

Program Management Plan

The production of a FILL follows a Program Management Plan. This plan outlines the major actions that must take place, their scheduled completion dates, and the agency responsible for each. The scheduled dates are based on the effective date of the FILL which is determined by COMSURFLANT or COMNAVLOGPAC. An illustrative FILL Program Management Plan follows on the next several pages.

The Fleet CINC is responsible for nominating new and critical equipments to CNO for augmented supported. The critical equipments nominations are the result of CASREPT data supplied by FMSO. These nominations must be approved by CNO and are then passed to SPCC, via NAVSUP, for preparation of the override inputs. We detailed this process in Chapter III.

PMP MILESTONES SCHEDULED FOR COMPLETION

Chart No. PAC FILL (Edition)

FILL (Fleet Issue Load List) for U.S. Pacific Fleet

☐ OPTIMUM COSAL ☐ CONVENTIONAL COSAL

MAJOR COMPONENTS	DATE
Extract 24 month FILL demand	
Run FILL A/O E15 programs	
Distribute AFS supply aids	
Distribute FILL (Chapter IV of CARGO)	
NOTE: DATES HAVE BEEN OMITTED FROM THIS EXAMPLE	
BECAUSE OF CHANGES FROM LOAD TO LOAD.	
APPROXIMATE TOTAL TIMES IS 26 WEEKS.	

CODE
RELEASE DATE

Legend of Symbols
☆ AHEAD of SCHEDULE
○ ON SCHEDULE
☐ POSSIBLE DELAY
▽ NOT ON SCHEDULE

RESPONSIBILITY					ACTION MILESTONES	COMPLETION DATES		
DIRECT	SUPPORTING	MONITORING	No	SYM		SCHEDULED	EXTENDED	COMMENTS
COMNAV LOGPAC		FMSO	1		Provide effective date of FILL.			COMNAVLOGPAC approved by phone.
FMSO		FMSO	2		Provide a listing of 40 eqpmts experiencing CASREPTS in past 12 months in high to low sequence to COMNAVLOGPAC.			
COMNAV LOGPAC		FMSO	3		COMNAVLOGPAC nominate/recommend to CNO:			
				a	Weapons systems/new eqpmts for FILL augmented support			
				b	Number and positioning of FILLs			
				c	Fleet support factors			
SPCC		FMSO	4		Expedite availability of NMDF tapes E25KZ4, CNC Distribution No. 609, approximate mail date			
FMSO		FMSO	5		Provide latest supply aids distribution list to COMNAVLOGPAC for approval.			
NAVSUP		FMSO	6		Designate eqpmt approval for FILL support augmentation via override to ICPs/FMSO.			

RESPONSIBILITY					ACTION MILESTONES	COMPLETION DATES		
DIRECT	SUPPORTING	MONITORING	No.	SYM		SCHEDULED	EXTENDED	COMMENTS
COMNAV LOGPAC		FMSO	7		Expedite submission of FILL demand data to reach FMSO by			
COMNAV LOGPAC		FMSO	8		Provide the following:			
				a	List of items to be excluded from the FILL due to AFS storage or transfer problems.			
				b	List of items with maximum FILL quantities due to AFS space constraints.			
NAVSUP		FMSO	9		Provide the following:			
				a	Fleet support factor			
				b	Number of authorized FILLs			
				c	Location of FILLs			
COMNAV LOGPAC		FMSO	10		Advise FMSO of supply aids distribution approval.			
COMNAV LOGPAC		FMSO	11		Advise AFSs to hold CNC distribution No. 610 ( ) approximate mail date 1976; and No. 611 ( ) approximate mail date and subsequent CNCs for application to new FILL supply aids.			
SPCC		FMSO	12		Provide override inputs for complete range of CNO approved eqpmts of Milestone No. 6 (E22 format deck and listings).			
FMSO		FMSO	13		Extract 24 months FIRL demand from A/O E22 files for through Ensure "I" cog demand for this 24 months period has been forwarded to NAVPUBFORMCEN.			
FMSO/		FMSO	14		Begin production of PAC FILL under A/O E15.			

RESPONSIBILITY					ACTION MILESTONES	COMPLETION DATES		
DIRECT	SUPPORTING	MONITORING	No.	SYM		SCHEDULED	EXTENDED	COMMENTS
FMSO		FMSO	15		Provide preliminary FILL Add deck to SPCC,			
SPCC	570				DSCs for review and comments.			
DCSC								
DESC								
DGSC								
DISC								
DPSC	9L/9D							
NPFC		FMSO	16		Provide FILL "I" Cog inputs based on			
					through demand to FMSO (list-			
					ings and cards with zeros in cc 42-51, "0" in			
					price code cc 72 and prices in all cards			
					including deletes).			
SPCC		FMSO	17		Provide results of review of Milestone 15.			
DCSC		FMSO	18		Provide results of review of Milestone 15.			
DESC								
DGSC								
DISC								
DPSC	9L/9D							
SPCC		FMSO	19		Apply post model changes.			
FMSO		FMSO	20		Provide FILL statistics to NAVSUP.			
NAVSUP		FMSO	21		Advise FMSO of FILL approval prior to re-			
					lease of supply aids.			
SPCC		FMSO	22		Provide photomats for FILL (Chapter IV of			
					CARGO).			
FMSO		FMSO	23		Deliver photomats to printer.			
FMSO		FMSO	24		Distribute supply management aids.			
				a	MLSF ships (AFS)			
				b	ICP/DSCs			
				c	Ashore segments			
FMSO		FMSO	25		Distribute mechanized aids to other ships/			
					commands.			

RESPONSIBILITY					ACTION MILESTONES	COMPLETION DATES		
DIRECT	SUPPORTING	MONITORING	No.	SYM		SCHEDULED	EXTENDED	COMMENTS
FMSO		FMSO	26		Distribute FILL (Chapter IV of CARGO w/CARGO)			
FMSO		FMSO	27		Effective date of FILL.			

FMSO will also be notified by the Fleet CINC of items that are to be assigned Exclusion or Maximum Quantity overrides because of storage or transfer problems.

CNO must also approve the fleet's recommended numbers and positioning of FILLs and the Fleet Support Factor (the adjustment factor used to convert peacetime demand to expected wartime demand). After approval, FMSO is informed of these data for use in the Load List operations.

FIRL/FILL CANDIDATES

Merging the files

The first step in the UICP FIRL/FILL operation is to develop a consolidated list of FIRL/FILL candidates, the Master FIRL Candidate Record. This is done by merging the FIRL Demand Extraction File with the FIRL History File. As was discussed in Chapter II, the FIRL Demand Extraction should have been entered through the MLSF Demand operations so that they could be updated with management data from the NMDF and merged with the extracted demand.

At the time of the merging of the Demand Extraction File with the History File, the History File is updated by means of the NMDF Addendum File. This ensures that the History File will contain the most current and preferred stock numbers. Unit of issue changes are made where necessary and the procedure is the same as that discussed in

Chapter II. Any Fill Stock Number changes on the History File are retained so that they may be listed in the CARGO.

Additional overrides or changes may be entered at the time of the building of the Master FIRL Candidate Record.

After the merger process, if duplicate entries for the same item exist, they will be combined and their quantities added.

The file of Master FIRL Candidate Records becomes the input to the FIRL/FILL range and depth computations.

FIRL/FILL DEMAND AVERAGING

The FIRL/FILL demand forecasting procedure works with the FIRL Candidate data and an optional parameter card. This parameter card allows FMSO to select, at each running of the averaging procedure, how many quarters of historical demand data are to be used in the averaging process and the FIRL range cut. The parameter card also reflects a Load Activity Code (LAC) that identifies the specific Load List in process. For example, if the Load List being prepared is the Atlantic FIRL/FILL, the LAC would be FIRLA.

As each item is read from the FIRL Candidate Tape. a check is made of whether the item is an Exclusion Override and a count is kept of the number of such overrides.

The Total FIRL Demand for an item is the sum of the quarterly demands for the most recent N quarters. N is taken from the parameter card or, if no parameter card is used, is set at eight quarters.

Calculating the demand variables

The Total FIRL Frequency is found in the same way; the frequencies in each of the quarters of interest are added.

The average quarterly demand is just the simple average

$$\text{Average Quarterly FIRL Demand} = \frac{\text{Total FIRL Demand}}{N}$$

The FIRL Standard Deviation of Quarterly Demand, a measure of the variability of demand, is computed using the standard formulation

$$\sigma_{FIRL} = \sqrt{\frac{\sum_{i=1}^{N} \left[\begin{pmatrix}\text{FIRL Demand} \\ \text{in quarter } i\end{pmatrix} - \begin{pmatrix}\text{Average Quarterly} \\ \text{FIRL Demand}\end{pmatrix}\right]^2}{N-1}}$$

The FIRL Average Requisition Size is found by dividing the Total FIRL Demand by the Total FIRL Frequency.

$$A_{FIRL} = \frac{\text{Total FIRL Demand}}{\text{Total FIRL Frequency}}$$

The same values are found for the FILL demand data.

$$\text{Total FILL Demand} = \sum_{i=1}^{N} \text{FILL Demand in quarter } i$$

$$\text{Total FILL Frequency} = \sum_{i=1}^{N} \text{FILL Frequency in quarter } i$$

$$\text{Average Quarterly FILL Demand} = \frac{\text{Total FILL Demand}}{N}$$

$$\sigma_{\text{FILL}} = \sqrt{\frac{\sum_{i=1}^{N} \left[\begin{pmatrix} \text{FILL Demand} \\ \text{in quarter } i \end{pmatrix} - \begin{pmatrix} \text{Average Quarterly} \\ \text{FILL Demand} \end{pmatrix} \right]^2}{N-1}}$$

$$A_{\text{FILL}} = \frac{\text{Total FILL Demand}}{\text{Total FILL Frequency}}$$

If the Total FIRL or FILL Demand for an item is zero, the respective quarterly Demand Average, Standard Deviation, and Average Requisition Size are all set to zero.

If the Total FILL Frequency is greater than the Total FIRL Frequency, the following corrections are made

Total FIRL Demand = Total FILL Demand

Total FIRL Frequency = Total FILL Frequency

Average Quarterly FIRL Demand = Average Quarterly FILL Demand

Standard Deviation of FIRL Demand = Standard Deviation of FILL Demand

Average FIRL Requisition Size = Average FILL Requisition Size

FIRL Candidates With Forecasts Tape

When the demand averaging procedure is completed, a tape is prepared for use in computing the ranges and depths of the FIRL and the FILL. This tape file is essentially the Master Candidate Record file updated with the Average Quarterly Demand, both FIRL and FILL; the Standard deviation of demand, both FIRL and FILL; Total Frequency, both FIRL and FILL; and Average Requisition Size, both FIRL and FILL.

Frequency Distributions

Several frequency distributions are prepared for analysis purposes, primarily as an aid in determining the range cut values.

Types of freqeuncy distributions

The first frequency distribution enumerates the number of candidate items experiencing a particular FIRL frequency. It also shows the cumulative values for each frequency. For example, the cumulative number of items experiencing a frequency of 3 or more would be the sum of the number of items with a demand frequency of three, four, and so on up to the final value of 32 or greater.

There are four other distributions, all relating the total FIRL (expanded) frequency to the FILL (deployed) frequency. The distinction between the four is made on the

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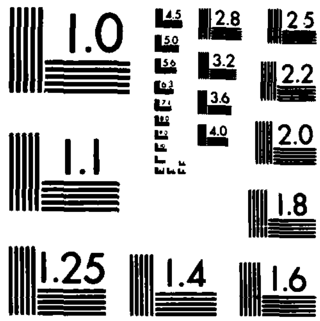
1.0
1.1
1.25
1.4
1.6
1.8
2.0
2.2
2.5
2.8
3.2
3.6
4.0
4.5
5.0
5.6

TOTAL CANDIDATE DISTRIBUTION

MAXIMUM VALUE OF TOTAL FIRL (EXPANDED) FREQUENCY IN CELL	0	1	2	3	4	5	6	7	8	9	10
NR ITEMS IN CELL	1144	65824	23540	12125	7806	5398	4220	3146	2483	2074	1735
CUMULATIVE NR OF ITEMS	148607	147463	81639	58299	46174	38368	32970	28750	25604	23121	21047
TOTAL FREQUENCY IN CELL	0	65824	47080	36375	31224	26990	25320	22022	19864	18666	17350
CUMULATIVE FREQUENCY	164975	164975	99351	52271	15896	984672	957682	932362	910340	890476	871810
PERCENT TOTAL FREQUENCY	1.000	1.000	0.943	0.903	0.872	0.845	0.822	0.800	0.781	0.764	0.748

	11	12	13	14	15	16	17	18	19	20	21
NR ITEMS IN CELL	1530	1210	1097	919	844	790	676	609	556	548	487
CUMULATIVE NR OF ITEMS	19312	17782	16572	15475	14556	13712	12922	12246	11637	11081	10533
TOTAL FREQUENCY IN CELL	16830	14520	14261	12866	12660	12640	11492	10962	10564	10960	10227
CUMULATIVE FREQUENCY	854430	837630	823110	808849	795983	783323	770683	759191	748229	737665	726705
PERCENT TOTAL FREQUENCY	0.753	0.719	0.706	0.694	0.683	0.672	0.661	0,651	0.642	0.633	0.623

	22	23	24	25	26	27	28	29	30	31	>31
NR ITEMS IN CELL	409	412	371	344	319	315	271	287	214	243	6861
CUMULATIVE NR OF ITEMS	10046	9637	9225	8854	8510	8191	7876	7605	7318	7104	6861
TOTAL FREQUENCY IN CELL	8798	9476	8904	8600	8294	8505	7588	8323	6420	7533	633837
CUMULATIVE FREQUENCY	716478	707680	698004	689100	680500	672206	663701	656113	647790	641370	633837
PERCENT TOTAL FREQUENCY	0.615	0.607	0.599	0.591	0.584	0.577	0.569	0.563	0.556	0.550	0.544

NUMBER OF CANDIDATE RECORDS 1,517

basis of whether the item is equipment-related or non-equipment-related and current FILL and previous FILL. For FIRL/FILL purposes, the distinction between equipment-related and non-equipment-related material is based on the store account (discussed below) and the Federal Supply Group (FSG). Each cell in one of these frequency distributions shows the cumulative number of items experiencing at total FIRL frequency of at least a certain value and a FILL frequency of at least another value. This concept is perhaps more easily understood if the sample equipment-related frequency distribution shown on page 5-13 is examined. The circled number indicates that 4899 items had a Total FIRL (expanded) Frequency of 9 or more and a Total FILL (deployed) Frequency of 4 or more.

FIRL/FILL LEVELS

Once the demand-related information for each candidate has been found, the Load List levels can be computed. A set of UICP decision rules have been developed to determine the range and depth of both the Fleet Issue Requirements List and the Fleet Issue Load List.

E R   F I L L   C A N D I D A T E S

NUMBER OF ER FILL ITEMS
WITH MAND/MIN OVERRIDE

1.250

TOTAL FILL (EXPANDED) FREQUENCY

TOTAL FILL (DEPLOYED) FREQUENCY	0	1	2	3	4	5	6	7	8	9	10
0.	12500	12500	12500	12500	12500	12500	12500	12500	12500	11100	9954
1.	9796	9796	9796	9796	9796	9796	9796	9796	9796	9033	8395
2.	7705	7705	7705	7705	7705	7705	7705	7705	7705	7333	6960
3.	6125	6125	6125	6125	6125	6125	6125	6125	6125	5957	5775
4.	4982	4982	4982	4982	4982	4982	4982	4982	4982	4099	4807
5.	4136	4136	4136	4136	4136	4136	4136	4136	4136	4091	4036
6.	3493	3493	3493	3493	3493	3493	3493	3493	3493	3472	3444
7.	3017	3017	3017	3017	3017	3017	3017	3017	3017	3006	2990
8.	2627	2627	2627	2627	2627	2627	2627	2627	2627	2622	2613
9.	2310	2310	2310	2310	2310	2310	2310	2310	2310	2309	2302
10.	2048	2048	2048	2048	2048	2048	2048	2048	2048	2047	2044
11.	1811	1811	1811	1811	1811	1811	1811	1811	1811	1811	1808
12.	1590	1590	1590	1590	1590	1590	1590	1590	1590	1590	1587
13.	1423	1423	1423	1423	1423	1423	1423	1423	1423	1423	1421
14.	1283	1283	1283	1283	1283	1283	1283	1283	1283	1283	1282
15.	1154	1154	1154	1154	1154	1154	1154	1154	1154	1154	1153
16.	1046	1046	1046	1046	1046	1046	1046	1046	1046	1046	1045
17.	958	958	958	958	958	958	958	958	958	958	958
18.	880	880	880	880	880	880	880	880	880	880	880
19.	803	803	803	803	803	803	803	803	803	803	803
20.	733	733	733	733	733	733	733	733	733	733	733
21.	666	666	666	666	666	666	666	666	666	666	666
22.	609	609	609	609	609	609	609	609	609	609	609
23.	562	562	562	562	562	562	562	562	562	562	562
>= 24.	531	531	531	531	531	531	531	531	531	531	531

The FIRL/FILL Range

The first step in the procedure is to determine the range of items to be included on the list. An item will be selected for a particular list if its demand frequency is greater than a specified level. This specified level is called a "range cut." There is actually a set of three range cuts used. There is a range cut for the FIRL and two range cuts for the FILL. To be included on the FIRL, the item's FIRL (expanded) demand frequency must be equal to or exceed the first range cut. To be included on the FILL, the item's FIRL demand frequency must be equal to or exceed the second range cut and its FILL (deployed) demand frequency must be equal to or exceed the third range cut. If the first range cut is satisfied but either the second or third is not, the item will be coded FIRL Only. The range cut check will be ignored if the item is a Mandatory or Minimum Quantity override.

Range cut

The FIRL/FILL Levels operation permits the introduction of either a combined set of range cuts or a separate set for APA, NSA-ER, and NSA-NER items. Separate range cuts have been used in the Load List operation over the past several years and this policy is expected to continue.

In those cases where the item's demand frequency is insufficient to be included on the FIRL, the item will be considered to be a non-Load List item and both the FIRL and FILL quantities will be set to zero.

Should the item be included on the FIRL but not the FILL (in other words, the item is FIRL Only), the FILL quantity will be set to zero.

If either of the situations discussed in the previous two paragraphs occur and the item was included on the previous FILL, the item is considered a FILL delete. The dollar value of each FILL Delete is computed.

Dollar Value = Unit Price x Previous FILL Quantity

and various statistics are accumulated. These include:

Number of APA FILL Deletes
Total Dollar Value of APA FILL Deletes
Number of NSA-ER FILL Deletes
Total Dollar Value of NSA-ER FILL Deletes
Number of NSA-NER FILL Deletes
Total Dollar Value of NSA-NER FILL Deletes
Overall Number of FILL Deletes
Overall Total Dollar Value of FILL Deletes

The operation has the option of considering an NSA-NER FIRL Only item as a non-Load List item. If this option has been selected, an NSA-NER that fails the FILL range cuts will not be included in the Load List even though its demand frequency exceeds or equals the FIRL range cut.

<u>The FIRL/FILL Depth</u>

After the decision has been made to include an item in the FIRL/FILL or FIRL Only range, the problem becomes one of determining the item's depth. The quantity of the item to be included in the Load List must be found.

The quantity of interest is the quantity required under wartime conditions over a designated period of time. Since the demand forecast and its standard deviation were based on a history of peacetime demands, they cannot be used in the depth calculations. Some adjustment must be made.

Fleet Support Factor

The adjustment is made through the introduction of a concept known as the Fleet Support Factor (FSF). This factor is a multiplier based on an estimate of how much higher than peacetime demand wartime demand will be. It represents the increased tempo of operations expected

during wartime. This estimate can be input at the time of Load List preparation. If it is not, the operation will automatically use an FSF of 1.5, indicating that wartime demand is expected to be 50 percent greater than peacetime demand.

Support Period

The Support Period (SP) is that period of time that the Load List is required to support the Fleet requirements. The Support Period is measured in quarters and can be introduced into the operation prior to Load List preparation. If no Support Period is input, the operation assumes the Support Period to be one quarter.

The adjusted wartime average demand over the Support Period becomes

$$\begin{matrix}\text{Wartime Average}\\ \text{Support Period Demand}\end{matrix} = \begin{pmatrix}\text{Peacetime Average}\\ \text{Quarterly Demand}\end{pmatrix} \times \begin{pmatrix}\text{Fleet Support}\\ \text{Factor}\end{pmatrix} \times \begin{pmatrix}\text{Support}\\ \text{Period}\end{pmatrix}$$

$$WAD_{sp} = QAD \times FSF \times SP$$

The adjusted wartime Support Period demand standard deviation is then:

$$\begin{pmatrix}\text{Standard Deviation of}\\ \text{Wartime Support Period Demand}\end{pmatrix} = \begin{pmatrix}\text{Standard Deviation of}\\ \text{Peacetime Quarterly Demand}\end{pmatrix} \times$$

$$\begin{pmatrix}\text{Fleet Support}\\ \text{Factor}\end{pmatrix} \times \begin{pmatrix}\text{Support}\\ \text{Period}\end{pmatrix}$$

$$\sigma_{WD} = \sigma_D \sqrt{(FSF) \times (SP)}$$

The depth of an item is made up of two components. First, there is the expected demand over the Support Period, WAD_{sp}. The other component can be considered a safety stock and depends on the item's expected demand, standard deviation of demand, and acceptable risk of using up the Load List quantity during the Support Period.

Acceptable Risk

The acceptable risk can be derived in several ways. One way is to determine the acceptable risk prior to the Load List computations for each type of item (APA, NSA-ER, and NSA-NER) and input these at the beginning of the operation. The depth will then be computed using these values.

A second way of determining the acceptable risk is to allow the operation to calculate an acceptable risk for each individual item based on the item type and the characteristics of the item. If this option is selected, there are two risk equations that can be used. One equation considers requisition effectiveness and gives the risk or probability of being unable to satisfy one or more requisitions during the Support Period. The other equation considers

unit effectiveness and computes the risk or probability of being one or more units short during the Support Period.

The requisition-related risk equation is

$$\text{Risk} = \lambda \frac{C x A}{WAD_{sp}}$$

λ = Risk Factor. A value for this factor must be input to the operations for each type of item. (We will talk more about this later.)

c = Unit Price

A = Average Requisition Size. Average number of units requested on a requisition.

WAD_{sp} = Wartime Average Demand during the Support Period.

The unit-related risk equation is:

$$\text{Risk} = \lambda \frac{C}{WAD_{sp}}$$

Constraining the risk

Whichever equation is used, the risk is constrained to be between a minimum and a maximum value. The operation has an option whereby minimum and maximum values may be input. If this option is not taken, the risk will be constrained to be no smaller than 0.02275 and no larger than 0.97725.

Now that a value of risk is available to the operation (whether input or computed), the operation is in a position to determine the Load List quantity for the item. In making this

Normal probability distribution

determination, the operation assumes that the Support Period demand for all items is normally distributed. For items with low demand forecasts, this assumption may not be valid but the operation ignores this possibility.

The FIRL depth of an item is

$$\text{Load List Quantity} = WAD_{sp} + t\sigma_{WD}$$

t = Safety Stock Factor. This factor depends on the normal probability distribution and the value of Risk. Appendix A shows how this computation is made. This appendix also gives a table relating t to the Risk.

The computed Load List Quantity is set to one (1) if the value calculated is less than one and is rounded to the nearest whole number if the value is greater than one.

If you look at the table, you can see that a Risk of .5 gives a t of zero. In this case, the Load List quantity is equal to the Average Wartime Demand during the Support Period. No safety stock will be carried. Since the normal probability curve is symmetrical about its middle, the probability of being below the middle is 50 percent and the probability of being above the middle is 50 percent. This means that half the time we won't have enough stock to

satisfy the demands during the Support Period and half the time we will. We are taking a 50-50 chance of being unable to satisfy the Fleet. This is what a Risk of 0.5 means.

As the Risk gets smaller, the t factor increases. In other words, the smaller we want to make the chance of not being unable to meet the Fleets' demands, the more safety stock has to be included in the item's depth. We will have a larger and larger positive safety stock.

On the other hand, if the Risk is greater than 0.5, the t factor is negative and becomes more negative as Risk increases. In this case, we are willing to take more than a 50-50 chance of depleting our load list and the Load List Quantity is less than the Wartime Average Demand during the Support Period.

Comparing with previous value

Once the Load List Quantity has been calculated, a comparison is made with the previous depth value. If the item is a FIRL Only item, the comparison is made between the new FIRL Depth (the Load List Quantity) and the previous FIRL Depth. If the item is a FILL item, the comparison is made between the new FILL Depth and the previous FILL Depth.

For a FILL item, the new FILL Depth is:

$$\text{New FILL Depth} = \frac{\text{Load List Quantity}}{N} \quad \text{(Rounded to nearest whole number)}$$

N = Number of FILLs. An input value dependent on the Fleet for which the Load List is being prepared.

The comparisons are made as follows:

1. If the old depth value was less than or equal to five units, the old value will be used on the new Load List unless the new value differs from it by more than three units.

2. If the old depth value was more than five units but less than or equal to ten units, the old value will be used on the new Load List unless the new value differs from it by more than four units.

3. If the old depth value was more than ten units but less than or equal to 20 units, the old value will be used on the new Load List unless the new value differs from it by more than five units.

4. If the old Depth value was more than 20 units, the old value will be used on the new Load List unless the new value differs from the old value by more than a certain percentage. This percentage must be input to the operation.

This comparison is the final determination of the Load List quantity unless the item is an override item. An item that is to be considered for the FIRL/FILL and that has a Mandatory Quantity override will be given the following FILL Depth:

Introducing overrides

$$\text{New FILL Depth} = \frac{\text{Override Quantity}}{N} \quad \text{(Rounded to nearest whole number)}$$

An item not coded FIRL Only with a minimum quantity override will also be assigned a FILL Depth of:

$$\text{New FILL Depth} = \frac{\text{Override Quantity}}{N} \quad \text{(Rounded to nearest whole number)}$$

unless the FILL Depth computed using the Risk is greater. In this latter case, the Risk-related FILL Depth will be used.

An item with a Maximum Quantity Override quantity will have its depth determined using the override quantity unless the Risk related depth is less than the override depth. In this case, the Risk-related FILL Depth will be used.

Once the new FILL Depth has been found, the new FIRL Depth is computed

$$\text{New FIRL Depth} = (\text{New FILL Depth}) \times N$$

FIRL Only items with overrides will have their depths adjusted for the override quantity in a similar fashion. This means that for a Mandatory Quantity Override, the FIRL Only quantity will be the override quantity; for a Maximum Quantity Override, the FIRL Only quantity can be no greater than the override quantity; and, for a Minimum Quantity Override, the FIRL Only quantity must be at least as large as the override quantity.

Collecting statistics

Now that the depth of the item has been found, the operation turns to the accumulation of statistics. Depending on an item's characteristics, it will be added to either the FIRL Only Range or the FILL Range and then added to the Total FIRL Range.

The item's Wartime Average Support Period Demand will be added to that of items of the same type; either APA, NSA-ER, or NSA-NER.

The item's FIRL Frequency will be adjusted for wartime conditions (Fleet Support Factor, FSF) and for the Support Period (SP).

$$\text{Wartime Support Period FIRL Frequency} = \frac{\text{(Total Peacetime FIRL Frequency)} \times \text{(FSF)} \times \text{(SP)}}{8}$$

This adjusted frequency will be accumulated for items of the same type.

The Wartime Average Support Period Demand and Frequency are also computed for non-Load List items and accumulated by type.

The extended dollar value of the FILL quantity of the item is computed if it is to be included on the FILL.

$ Value of FILL Quantity = (New FILL Depth) x (Unit Price)

The FILL dollar values are accumulated for items of the same type.

If the item is a FILL ADD item, its FILL dollar value is added to the accumulated dollar value of FILL ADDs. An item is a FILL ADD item if it is included on the new FILL but was not on the previous FILL.

FIRL Only items also have their extended dollar values computed and accumulated.

The extended dollar value of FIRL Only items will also be accumulated in the Total FIRL Dollar Value. FILL items will have their FILL dollar value multiplied by N and then accumulated in the Total FIRL Dollar Value.

The expected number of units short must be found before the number of units satisfied or requisitions satisfied can be determined. The computations requires the use of normal probability distribution that we talked about earlier. The

three things we need to know are the new FIRL quantity, the Wartime Average Support Period Demand (WAD_{sp}), and the standard deviation of Wartime Support Period Demand (σ_{WD}). The computations are outlined in Appendix B.

Computing shorts and satisfieds

If the option to compute effectiveness in terms of units has been chosen, the expected units satisfied must be computed.

$$\text{Expected Units Satisfied} = \left(\begin{array}{c}\text{Wartime Average}\\ \text{Support Period Demand}\end{array}\right) - \left(\begin{array}{c}\text{Expected Units}\\ \text{Short}\end{array}\right)$$

The value computed for Expected Units Satisfied cannot be negative. If it is, it is set to zero. The Expected Units Satisfied are accumulated for items of the same type.

On the other hand, if effectiveness is to be measured in terms of requisitions, the expected number of requisitions short must be found.

$$\text{Expected Requisitions Short} = \frac{\text{Expected Units Short}}{\text{Average Requisition Size}}$$

The Expected Requisitions Short can be used to find the Expected Requisitions Satisfied by

$$\begin{array}{c}\text{Expected Requisitions} \\ \text{Satisfied}\end{array} = \left(\begin{array}{c}\text{Wartime Support Period} \\ \text{FIRL Frequency}\end{array}\right) - \left(\begin{array}{c}\text{Expected Requisitions} \\ \text{Short}\end{array}\right)$$

The value for Expected Requisitions Satisfied will be set to zero if the calculation produces a negative value.

There can be up to three different risk values used for each type of item in determining the Load List quantities and accumulating statistics. Either three different value of λ may be input for each type of item (APA, NSA-ER, and NSA-NER) or three different values of fixed Risk may be input for any or all of the three item types. These values are input prior to processing.

By making the computations with three different values for Risk, the impact of the Risk constraint can be examined in terms of cost and effectiveness. As the Risk is lowered, the effectiveness should increase but so should the cost. When we attempt to increase the unit or requisition effectiveness by accepting a lower chance of stock-out, it will cost us money since the Load List depths will have to be larger.

After all the candidate items have been examined for all three risk values, some overall statistics are accumulated. These include:

1. Total FILL Range = APA FILL Range = NSA-ER FILL + NSA-NER FILL Range

2. Total FIRL Only Range = APA FIRL Only Range + NSA-ER FIRL Only Range + NSA-NER FIRL Only Range

3. Total FIRL Range = Total FILL Range + Total FIRL Only Range

4. Total FILL ADDs = APA FILL ADDs + NSA-ER FILL ADDs + NSA-NER FILL ADDs

The dollar value of the items associated with the above four categories must also be computed. However, the dollar value will depend on the Risk settings; the dollar value depends on the Depth as well as the Range and the Depth, in turn, depends on the Risk. So there are four sets of cost-related statistics. Each set has three different values resulting from three different Risk settings.

5. \$ Value of FILL ADDs = \$ Value of APA FILL ADDs + \$ Value of NSA-ER FILL ADDs + \$ Value of NSA-NER FILL ADDs

6. \$ Value of FILL = \$ Value of APA FILL + \$ Value of NSA-ER FILL + \$ Value of NSA-NER FILL

7. \$ Value of FIRL Only = \$ Value of APA FIRL Only + \$ Value of NSA-ER FIRL Only + \$ Value of NSA-NER FIRL Only

8. \$ Value of FIRL = \$ Value of FIRL Only + N x (\$ Value of FILL)

The Support Period demand is accumulated for both Load List and non-Load List items. Similarly, the Support Period frequencies for both Load List and non-Load List items are accumulated. With these values, the effectiveness of the Load List can be measured.

Computing effectiveness

If Unit Effectiveness is the option selected, the Net Unit Effectiveness will be

$$\text{Net Unit Effectiveness} = \frac{\text{Total Units Satisfied}}{\text{Total Support Period Load List Demand}}$$

Total Units Satisfied = APA Expected Units Satisfied + NSA-ER Expected Units Satisfied + NSA-NER Expected Units Satisfied

The Net Unit Effectiveness measures what fraction of demand over the Support Period for the items included on the FIRL will be satisfied. The Net Unit Effectiveness will depend on the Risk value selected since its major component, Total Units Satisfied, depends on Risk.

Also computed is the Gross Unit Effectiveness:

$$\text{Gross Unit Effectiveness} = \frac{\text{Total Units Satisfied}}{\left(\begin{array}{l}\text{Total Support Period}\\ \text{Load List Demand}\end{array}\right) + \left(\begin{array}{l}\text{Total Support Period}\\ \text{non-Load List Demand}\end{array}\right)}$$

Here we are measuring the fraction of demand for all candidates, whether they have been included on the Load List or not, that will be satisfied by the Depth of the FIRL.

If the effectiveness option selected has been for Requisition Effectiveness, the Net Requisition Effectiveness can be found from

$$\text{Net Requisition Effectiveness} = \frac{\text{Total Requisitions Satisfied}}{\text{Total Support Period Load List Freq.}}$$

Total Requisitions Satisfied = APA Expected Requisitions Satisfied + NSA-ER Expected Requisitions Satisfied + NSA-NER Expected Requisitions Satisfied.

This measures the percentage of requisitions for the Load List items that are expected to be satisfied.

The Gross Requisition Effectiveness is:

$$\text{Gross Requisition Effectiveness} = \frac{\text{Total Requisitions Satisfied}}{\left(\begin{array}{l}\text{Total Support Period}\\ \text{Load List Frequency}\end{array}\right) + \left(\begin{array}{l}\text{Total Support}\\ \text{Period non-}\\ \text{Load List Freq.}\end{array}\right)}$$

Evaluation of Effectiveness Calculation

Adjusting the Risk parameters

Regardless of the effectiveness measure being used, once the computations are complete and printed, the calculated effectiveness is compared to the desired objective. If the calculated effectiveness does not meet the objective (it is either too low or too high), the risk parameters are adjusted as a result of analysis by FMSO personnel and the calculations are repeated. This adjustment and recomputation will continue until the objective is met.

PRELIMINARY LOAD LIST OUTPUTS

After the range and depth computations are completed, SPCC is provided with information regarding additions to the FILL. SPCC reviews this information and makes changes as necessary. FMSO also reviews the preliminary outputs relative to the Cogs for which they are responsible.

If you recall our discussion of demand collection in Chapter II, you will remember that I Cog demand data was forwarded to NPFC. NPFC is responsible for making range and depth calculations regarding this material. Its FILL inputs are provided to FMSO.

The changes resulting from the SPCC and FMSO reviews and the inputs from NPFC are entered on the Load List files through a files maintenance procedure.

After these files maintenance changes have been made, the FILL statistics are forwarded to NAVSUP for approval. Once approval is received, production and distribution of the final Load List products begins.

FINAL LOAD LIST OUTPUTS

There are two final outputs of the FIRL/FILL process. They are the Supply/Management Aid Records and Chapter IV of the Consolidated Afloat Requisitioning Guide, Overseas.

Supply/Management Aid Records

SMAR

SMARs are distributed to the Combat Stores Ships and ashore locations associated with the fleet for which the FILL is being prepared. They are also sent to those ships that are equipped with U1500 computers. As their name implies, these records are intended to assist the MLSF ships and activities in performing their mission. The records can be distributed in either card or tape form depending on the recipient's data processing capability.

Consolidated Afloat Requisitioning Guide, Overseas

CARGO

The UICP FILL process, combined with SPCC review and I Cog inputs from NPFC, provide the necessary information to publish Chapter IV of the CARGO. This guide provides the Fleet with a shopping list of the items available from the MLSF Combat Store Ships. This chapter of the CARGO

also contains a listing of Stock Number changes, relating the old Stock Number, with which the requisitioner might be familiar, to the new Stock Number.

Chapter IV, of course, is not the only chapter of the CARGO. FMSO is responsible for publishing the entire CARGO. It is not responsible, however, for preparing the other chapters. These chapters are prepared by COMSURFLANT (or COMNAVLOGPAC), NRSO, and NFSSO.

CARGO Quarterly Supplements

Quarterly Supplement

Since the FIRL/FILL operation and the publication of the CARGO are done annually, changes in the patterns of demand for particular item or the emergence of problem equipments may cause the FILL to no longer adequately meet the Fleet's requirements. For this reason, analyses of the demand and CASREPT data are performed, changes to the FILL are made and a quarterly supplement to the CARGO is published.

The quarterly revision of the FILL is predominately a manual, rather than a mechanized, process. It begins with an examination of the demand data for the prior three months as well as CASREPT data. These data are provided by FMSO to SPCC's Allowance Division which performs the necessary analyses and recommends changes to the FILL.

Financial statistics

Financial statistics regarding the changes in the FILL are supplied NAVSUP for approval. Once this financial approval is obtained, a listing of the items to be added or deleted are forwarded to the Fleet Commander for his approval.

When the Fleet Commander's approval is given, the changes are put in the proper format and become Chapter IV of the supplement. This is combined with the contributions from the other sources to make up the entire CARGO supplement. The supplement is published and distributed.

Supply/Management Aid Records related to the Load List changes are also supplied the affected MLSF ships and activities.

VI

TENDER AND REPAIR SHIP LOAD LISTS

Tender and Repair Ship Load Lists (TARSLLs) are produced by FMSO to enable the tenders and repair ships to meet their industrial mission. By industrial mission, we mean the repair of equipments on board the ships for which the tenders are responsible. The resupply mission of a submarine tender is also considered in the development of its TARSLL.

Types of TARSLL

There are two different types of TARSLLs. A hull (or ship)-tailored TARSLL is constructed for a specific tender or repair ship that has been assigned support responsibility for specific ships. At the current time, hull-tailored TARSLLs are constructed only for tenders and activities supporting submarines.

The second type of TARSLL is designated ocean-tailored. This TARSLL is prepared to support a specific set of ship types of either the Atlantic or Pacific Fleet. The load is placed on all the tenders or repair ships that support that set of ship types.

Program Management Plan

The construction of a TARSLL follows a Program Management Plan (PMP) similar to the one used in developing a FILL. A generalized TARSLL PMP is shown on the next two pages.

The first requirement is for the Type Commander (TY-COM) to supply all parties concerned in the development of the Load List with the hull mix to be supported by the load, the supply aid requirements, and the Load List distribution list NAVSUP provides the desired range cuts.

ICP File data

The hull mix, after concurrence by NAVSUP, will be used by SPCC to extract the necessary candidate data from the Weapons System File. Level A of the WSF provides the Allowance Parts Lists (APLs) associated with the ships making up the hull mix. Level C of the WSF is then used to obtain the items contained in the APLs. These items make up the candidate list.

Once the individual candidates have been obtained from the Weapon Systems File, the Master Data File or Program Support Interest File is accessed for additional information about each item that will be necessary for the Load List construction.

A candidate record is shown on the next page with the source of each data item noted.

FMSO has the responsibility for extracting the demand history for the candidates. The MLSF Master Demand File is accessed using the UICs of the tenders or repair ships

PMP MILESTONES SCHEDULED FOR COMPLETION

Chart No ______

☐ OPTIMUM COSAL ☐ CONVENTIONAL COSAL

MAJOR COMPONENTS

MAJOR COMPONENTS	DATE
"T" is the effective TARSL date, all timeframes will be in relation to "T" and will not be holidays or weekends.	
"T" - # is "T" minus # of weeks.	
PMP will be provided ALCON NLT "T" - 28	

CODE
RELEASE DATE

Legend of Symbols
☆ AHEAD of SCHEDULE
○ ON SCHEDULE
☐ POSSIBLE DELAY
▽ NOT ON SCHEDULE

RESPONSIBILITY DIRECT	SUPPORTING	MONITORING	NO	SYM	ACTION MILESTONES	COMPLETION DATES SCHEDULED	EXTENDED	COMMENTS
TYCOM	NAVSUP	FMSO	1		Advise ALCON of following:	"T"-26		Hull mix will be provided SPCC six weeks prior to SPCC's first milestone date and no later than the 10th of the month.
				a	Hull mix			
				b	Supply aid requirements			
				c	load list distribution			
NAVSUP TYCOM	FMSO		2		The following are from previous load list:	"T"-26		If anyone takes exception to these cutoffs, provide appropriate substitutes by this milestone date. Otherwise, concurrence will be assumed.
				a	Component cut.			
				b	Maintenance level cutoff.			
				c	Range cut.			
NAVSUP	FMSO		3		Provide FMSO 9111 with special requirements, if any, and hull mix concurrence.	"T"-25		
SPCC (572)		FMSO	4		Extract and produce candidates data and provide identification of E01WX2 and E17CZ1 tape files to FMSO 9111	"T"-19		Will be provided on the 26th of a month at the earliest.
[illegible]	SPCC	FMSO	5		Extract 24 months appropriate demand data from E22 files.	"T"-16		

RESPONSIBILITY					ACTION MILESTONES	COMPLETION DATES		
DIRECT	SUPPORTING	MONITORING	No.	SYM		SCHEDULED	EXTENDED	COMMENTS
SPCC (572)		FMSO	6		Provide FMSO 911 with E17GD1C change cards resulting from manual review of candidates data in milestone 4.	"T"-16		Will be provided on the 16th of the month at the earliest.
FMSO	SPCC	FMSO	7		Consolidate and update demand, load list changes, SPCC candidate input and SHIF with the NMDF (E17HW).	"T"-15		
FMSO	SPCC	FMSO	8		Process simulation/computation	"T"-14		
FMSO		SPCC	9		Forward the following listings to SPCC:	"T"-13		
				a	Load list review listing (E17MA1L) (E17RC1L)			
				b	Load list SKIM listings (E17LD1L) (E17LE1L) (E17LF1L) (17LG1L) (E17LE1L)			
				c	Error Listings (E17HD1L) (E17RD1L)			
SPCC (572)		FMSO	10		Forward changes resulting from manual review "T"-10 of listings provided in milestone 9.	"T"-10		
FMSO	SPCC	FMSO	11		Apply post-model changes	"T"-9		
FMSO		NAVSUP	12		Forward statistics to NAVSUP 013 and 034	"T"-8		
NAVSUP		FMSO	13		Provide FMSO with approval of financial statistics forwarded in milestone 12.	"T"-6		
FMSO		FMSO	14		Prepare supply aids in accordance with NAVSUP standard 5230.7	"T"-5		
FMSO		FMSO	15		Forward mats to printer	"T"-4		
FMSO		FMSO	16		Distribute supply aids in accordance with information provided in milestone 1.	"T"-4		
FMSO		FMSO	17		Distribute publication in accordance with information provided in milestone 1.	"T"		

that will be carrying the load or by the UICs of the hulls to be supported. For a hull-tailored Load List demand is extracted using the UICs of the hulls to be supported. If the load being constructed is an ocean-tailored TARSLL, the demand data may come from a number of tenders or repair ships. The necessary UICs are provided FMSO by NAVSUP.

Three "cuts"

There are three "cuts" involved in determining whether an item should be considered for inclusion in a TARSLL. Data regarding these "cuts" are required before the Load List can be built. FMSO is provided with values for these cuts from NAVSUP.

The first cut is the "component cut." This value designates, the minimum number of ships, of those supported by the TARSLL, that must reflect a specific component application.

The second cut is the "maintenance cut." An equipment-related item must be installable by the load activity personnel before it can be included on a TARSLL. This maintenance cut decision is based on DEN D013A (Use Maintenance Code) found in the MDF and PSI. This code indicates lowest maintenance level authorized to remove and replace an item. If an item cannot be installed by the load activity personnel, it is dropped from Load List consideration. In addition, the maintenance cut determines if the item must be installed at the load activity level or if it can be installed by the supported ship level.

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COG	FSC	NIIN	ITEM NAME	UI	SC	U PRICE	NIIN POP-D028-SHIP-REP FIRST	SECOND	THIRD	NIIN POP-D028A-IDR-REP FIRST	SECOND	THIRD	OVERRIDE CODE	QTY	RIC	ER/NEP
9Z	5310	000193509	WASHER,LOC	HD	PA	19	1								0194300001	R
9N	5915	000193571	NETWORK,HY	EA	PA	87700	1								287850027	R
2N	5905	000190673	NETWORK,SP	EA	PA	180000	1								287850027	R
2N	5905	000190674	NETWORK,SP	EA	PB	54800	1								287850027	R
2N	5905	000190675	NETWORK,SP	EA	PB	143000	1								287850027	R
2N	5905	000190632	NETWORK,SP	EA	PB	97700	4								287850027	R
9G	5977	000190748	BRUSH,ELEC	AY	PA	2301	24								833000609 833000808 833000852	R
9N	5950	000190830	COIL,RADIO	EA	PB	1969	3								52356800	R
1N	5845	000190831	ELECTRONIC	EA	PB	26500	2								57089485	R
1N	5845	000190856	VANE,SWITC	EA	PA	730	4								88875601	R
9G	3020	000190859	GEAR,BEVEL	EA	PB	750	2								59005306	R
1N	5925	000190861	ELECTRONIC	EA	PA	4100	1								59005309	R
9G	3020	000190863	GEAR,SPUR	EA	PB	245	11								59005300	R
9N	5945	000190875	RELAY,THER	EA	PA	2194	4								252760086	R
9N	5961	000191186	SEMICONDUC	EA	PA	289	7								61728411	R

CANDIDATE LISTING

The "range cut" is the final cut and is some minimum demand or demand frequency level that must be exceeded before an item can be considered for the load.

Review of candidate listing

Before any computations are made, SPCC's Allowance Division and FMSO's Load List Branch review the candidate listing, comparing the listing with the override files. These override files contain records of items that are not to be included on particular loads. They represent a compilation of information from NAVSUP and TYCOMs.

The demand extract is also reviewed by FMSO. Here, the purpose is to correct any gross errors in the demand data.

TARSLL RANGE AND DEPTH COMPUTATIONS

There is a great deal of similarity between the procedures used to compute the TARSLL Range and Depth and those used to compute the FIRL/FILL Range and Depth. Again, the objective is to determine the quantity of stock required by the tender or repair ship to support the Fleet for some desired period of time at some desired level of effectiveness. However, in this case, the support being provided is repair support (in most instances) rather than resupply support.

PWRS and POS

There are two distinct sets of TARSLL procedures; one for conventional tenders and repair ships and one for FBM tenders and repair ships. Conventional tender Load Lists are part of the Prepositioned War Reserve Stock (PWRS) while those of FBM tenders are part of the Peacetime Operating Stock (POS). In either procedure, experienced demand can be increased by a factor that represents the tempo of wartime requirements. However, historically, this value has been set to one and, as a consequence, unfactored experienced demand is used.

Whereas, the FIRL/FILL procedures divided items into three types (APA, NSA-Equipment Related, and NSA-Non-Equipment Related), the TARSLL procedures only distinguish between Equipment Related (ER) and Non-Equipment Related (NER) items. The APA/NSA distinction can be extracted later for statistical purposes using the Cog Symbol.

As with the FIRL/FILL procedures, Load Lists developed by the TARSLL procedures can be evaluated in terms of unit or requisition effectiveness measured in either the gross or net sense.

DEMAND FORECAST

We are going to discuss, in turn, the three methods for determining the demand forecast and its standard deviation for Load List Candidates.

The Simple Average

The simple average method of computing a demand forecast consists of first adding up the quarterly demands for an item for the past M quarters. M is an input value that can be as large as 8, the maximum number of quarters of history on the NMLF Demand History File. The simple average is found by taking the total obtained by adding the quarterly demands and dividing it by M. So,

$$\text{Quarterly Demand Forecast} = \frac{\sum_{i=1}^{M} D_i}{M}$$

D_i = Demand for the item for the ith quarter in the past.

If the simple average is not greater than zero, the Best Replacement Factor forecast will be used.

The Smoothed Forecast

This method, used only in the conventional tender procedures, requires the use of a smoothing weight, α. The value of this weight determines how much of an impact the demand for each of the previous quarters will have on the forecast. The value of the smoothing weight is an input value. If α is large, the most recent demand observations will have the greatest impact on the forecast. The opposite is also true. The value of x must be between zero and one.

The smoothed demand forecast is:

$$\text{Quarterly Demand Forecast} = \sum_{i=1}^{M-1} \alpha\,(1-\alpha)^{i-1} D_i + (1-\alpha)^{M-1} D_M$$

If the smoothed demand forecast is not greater than zero, the Best Replacement Factor forecast will be used.

The Best Replacement Factor Forecast

Population and BRF

This forecasting procedure requires the knowledge of the value of the BRF for the item. It also uses the item's population that is fleet installable (POP_s) and its population that is tender installable (POP_t). POP_t is that population of the item or supported ships that is used in applications in which the Maintenance Code indicates that the lowest level at which the item can be "removed and replaced" is the intermediate (tender) level. POP_s is the same except that the item can be removed and replaced at the organizations (ship) level. We also need to know the fraction (K_2) of the item's fleet installable population and the fraction (K_3) of the item's tender installable population that are supported by the tender.

In equation form:

$$\text{Quarterly Demand Forecast} = \frac{BRF}{4}\,[(POP_s) \times K_2 + (POP_t) \times K_3]$$

If the forecast is zero or less, it is set to 0.001 unit/quarter for conventional tenders and to 0.0 for FBM tenders. Should this occur, the forecast is designated a "forced" forecast.

Standard Deviation of Quarterly Demand

If the simple or smoothed average has been used to calculate the forecast, the standard deviation is computed using the demand observations. An exception to this would be the case where only one or two observations were used to compute the average. We will cover this case later.

In the case where there were three or more observations used in computing the demand forecast, the standard deviation is:

$$\sigma = \sqrt{\frac{\sum_{i=1}^{M}(D_i - \text{Quarterly Demand Forecast})^2}{M - 1}}$$

If the BRF Forecast procedure was used or if one of the other procedures was used with less than three observations, the standard deviation is directly related to the forecast.

If the forecast is one unit per quarter or more, the standard deviation is:

$\sigma = 1.6 \times$ (Quarterly Demand Forecast).

If the forecast is less than one unit, the computation of the standard deviation will be:

$$\sigma = 2.1 \times \text{(Quarterly Demand Forecast)}.$$

If the BRF Forecast was forced to be 0.001, the standard deviation will be set to 0.0001.

Total Demand Frequency

The Total Demand Frequency, when a forecasting procedure other than BRF is used, will be the sum of the quarterly frequencies over the M quarters.

$$H = \sum_{i=1}^{M} F_i$$

F_i = Demand frequency in quarter i.

If the BRF Forecast is used, the Total Demand Frequency will be set to zero.

Average Requisition Size

The Average Requisition Size is of importance only if we are measuring effectiveness in terms of requisitions satisfied. If the effectiveness is in terms of units satisfied, the procedures use an Average Requisition Size of one. This will also be the case if the forecast had been produced by the BRF process.

The Average Requisition Size in the case of requisition effectiveness is:

$$\text{Average Requisition Size} = \frac{\text{Total Demand}}{\text{Total Demand Frequency}}$$

LEVELS COMPUTATION

The procedures for computing depth differ between conventional tenders and FBM tenders. Therefore, we will talk about the depth calculations separately.

Range Selection for Conventional Tenders

Range cut options

There are three permissible options for deciding whether an item falls within the Range of the Load List. First, we may opt to have no range cut criteria at all. Every candidate item will be considered in the Depth calculations. However, a particular item may not be included in the Range if the computed load quantity is zero or negative.

The second option is to include in the preliminary Range every item whose demand forecast exceeds a certain input value. Depending on the Deptn calculations, an item may or may not be included in the final Range.

The final option is to make the preliminary Range decision based on the item's Total Frequency. If the item's Total Frequency

does not meet a threshold, again an input value, it will not be included in the Range.

Of course, if the item has been entered through, a Mandatory or Minimum Value Override, the item will be included in the range and the depth calculations will be made.

Depth Calculation for Conventional Tenders

The depth on conventional tender Load Lists is defined as the Prepositioned War Reserve Stock. Since we are interested in resupply capability under wartime conditions, we must translate the requirements (the demand) into wartime terms. This translation uses a Tempo Factor and a Support Period similar in concept to but not the same as the Fleet Support Factor and the Support Period used in the FIRL/FILL process. As we stated earlier, the Tempo Factor has historically set to one.

Tempo Factor

The translation depends on whether the Load List is being prepared for an Attack Submarine Tender or for either a Destroyer Tender or a Repair Ship. For an Attack Submarine Tender, the wartime demand forecast for the Support Period becomes:

$$WAD_{SP} = \text{Quarterly Demand Forecast} \times \text{Tempo Factor} \times \text{Support Period}$$

and its standard deviation is:

$$\sigma_{WD} = \sigma \times \sqrt{\begin{matrix}\text{Tempo} \\ \text{Factor}\end{matrix} \times \begin{matrix}\text{Support} \\ \text{Period}\end{matrix}}$$

If the Load List is being prepared for a Destroyer Tender or Repair Ship, the translated demand forecast is the same.

$$WAD_{SP} = \begin{matrix}\text{Quarterly Demand} \\ \text{Forecast}\end{matrix} \times \begin{matrix}\text{Tempo} \\ \text{Factor}\end{matrix} \times \begin{matrix}\text{Support} \\ \text{Period}\end{matrix}$$

but the standard deviation is slightly different:

$$\sigma_{WD} = \sigma \times \begin{matrix}\text{Tempo} \\ \text{Factor}\end{matrix} \times \sqrt{\begin{matrix}\text{Support} \\ \text{Period}\end{matrix}}$$

In both cases, the Total Demand Frequency is adjusted.

$$H_{SP} = H \times \begin{matrix}\text{Tempo} \\ \text{Factor}\end{matrix} \times \begin{matrix}\text{Support} \\ \text{Period}\end{matrix}$$

Essentiality

As we will see below, a Relative Item Essentiality is required in the computation of the acceptable level of risk. A value of 1.0 is used if the item's demand forecast is based on historical data. If the forecast was computed using the BRF, an attempt will be made to compute a Relative Item Essentiality using a weighted average of the Item Essentiality of the portion of the population that can be installed at the organization level and the Item Essentiality of the portion of the population that can be installed at the tender

level. These two population-related Item Essentialities are functions of the average Military Essentiality Codes for the two populations. The Relative Item Essentiality will be set to one if any of the population or MEC data needed to compute it is missing.

Acceptable risk

The acceptable level of risk if effectiveness is being measured in terms of requisitions satisfied is:

$$\rho = \frac{\lambda_4 C^A}{E \times (WAD_{SP})}$$

where λ = risk parameter which may be different for ER and NER items.

C = unit price (B053)

A = Average Requisition Size (=1 for BRF forecasts)

E = Relative Item Essentiality

WAD_{SP} = Wartime Demand Forecast (Note: in computing risk, a value of 1.0 is used for WAD_{SP} in the case of a BRF forecast.)

The acceptable risk, if effectiveness is being measured in terms of units satisfied is:

$$\rho = \frac{\lambda \times C}{E \times (WAD_{SP})}$$

The calculate risk will be constrained to be between some minimum and maximum values which can be input. If the constraints are not input, the maximum and minimum limits will be 0.97725 and 0.02275.

A fixed level of risk may be input and the calculation by passed. When the risk is fixed in this manner, it will be the same for all items and will no longer depend on the characteristics of each individual item.

In the risk calculations, separate values of λ can be used for equipment-related and non-equipment-related items. Separate ER and NER fixed levels of risk may be input if that option is selected.

Normal probability distribution

Once the acceptable risk is computed, the depth can be found using the normal probability distribution, WAD_{SP} and σ_{WD}. You can refer again to Appendix A for a description of the mechanics used in computing this quantity. If a fractional value is computed, the depth will be rounded. The rounding procedures is as follows:

1. If a range cut is used, set all values less than one equal to one and round all members greater than one to the nearest whole number.

2. If no range cut is used, round all quantities between zero and one to one; round all quantities greater than one to the nearest whole number, and set all quantities less than or equal to zero to a value of zero.

Impact of Overrides on TARSLL Depth

Checking overrides

Once the preliminary depth value has been computed, a check of the Override Code is made. If the override is Mandatory, the depth is set equal to the mandatory quantity.

If the item has been coded with an Exclusion Technical Override and a depth greater than zero has been computed, the Load List quantity is set to zero.

Comparing with old depth

The computed depth is compared to the depth used on the old Load List. This comparison is the same used for the FIRL/FILL computations. Essentially what is happening is that, in order to keep the changes to a minimum, the old Load List quantity will be used unless the new Load List quantity differs significantly from it.

Once the comparison is completed, a check is made for a Minimum Quantity Override. If this override is present and the computed quantity is less than the override value, the Load List quantity will be set to the Override quantity.

The extended dollar value of the Load List quantity must be at least $1.00. If it is not, the quantity will be increased until the value is $1.00.

The Load List quantity will be rounded to the next highest multiple of the Minimum Replacement Unit Quantity. If a repair or overhaul requires a certain number of units — for example, a tune-up of an engine involves the replacement of twelve spark-plugs, the Load List should reflect this.

After these adjustments, if the item has a Maximum Override Code, the quantity will be adjusted downward should it exceed the maximum value.

There are also special constraints on the computed quantity that apply only to items with no historical demand (Total Demand and/or Total Frequency equal zero) and no override. These constraints limit the computed quantity to 50 units and the extended dollar value to $100.00 unless a higher MRU is applicable.

Load List Statistics for Conventional Tenders

Once the Load List quantity has been determined, the expected number of units short can be found using the mean and standard deviation of the support period demand and the Load List quantity. The quantity can not be less than zero. This procedure also uses the normal distribution and an example of the computation is given in Appendix B.

If the effectiveness is to be measured in terms of units satisfied, the expected number of units satisfied is:

$$\text{Expected Number of Units Satisfied} = WAD_{SP} - \left(\text{Expected Number of Units Short}\right)$$

The value of the expected number of units satisfied is constrained to be zero or greater. The value found is accumulated separately for equipment-related and non-equipment-related items. The Wartime Demand Forecasts are also accumulated for ER and NER items.

If the effectiveness is to be measured in terms of requisitions satisfied, the expected number of requisitions satisfied must be found. This first requires the calculation of the expected number of requisitions short:

Computing shorts and satisfieds

$$\text{Expected Number of Requisitions Short} = \frac{\left(\text{Expected Number of Units Short}\right)}{\left(\text{Average Requisition Size}\right)}$$

The expected number of requisitions satisfied is:

$$\text{Expected Number of Requisitions Satisfied} = \left(\text{Expected Number of Support Period Req.}\right) - \left(\text{Expected Number of Requisitions Short}\right)$$

$$\begin{array}{l}\text{Expected Number of} \\ \text{Support Period Req.}\end{array} = \left(\frac{\text{Total Demand Frequency}}{M}\right) \times \left(\begin{array}{l}\text{Tempo} \\ \text{Factor}\end{array}\right) \times \left(\begin{array}{l}\text{Support} \\ \text{Period}\end{array}\right)$$

The expected number of requisitions satisfied is constrained to being equal to or greater than zero.

The expected number of requisitions satisfied is accumulated for equipment-related and non-equipment-related items as is the expected number of Support Period requisitions.

In addition to the above mentioned factors, the following statistics are also accumulated for ER and NER separately:

1. Number of items on the Load List.
2. Extended Dollar Value of the Load List.
3. Number of items added to the Load List.
4. Extended Dollar Value of the Load List additions.
5. Number of Load List items that had the maximum Risk constraint applied.
6. Number of Load List that had the minimum Risk constraint applied.
7. Number of Load List items with forced forecasts.
8. Number of Load List items with BRF forecast.
9. Number of Load List items with avearge demand forecasts.
10. Number of Load List items with smoothed demand forecasts.
11. Number of Load List items whose Load List quantities are related to overrides. Accumulated separately for mandatory, maximum, and minimum overrides.

12. Number of non-Load List items.

13. Number of items deleted from the Load List.

14. Extended Dollar Value of deleted items.

15. Number of non-Load List items with BRF forecasts.

16. Number of non-Load List items with average demand forecasts.

17. Number of non-Load List items with smoothed demand forecast.

18. Number of non-Load List items with exclusion override.

19. Wartime Average Demand for non-Load List items.

20. Total Frequency for non-Load List items.

21. Number of non-Load List items that had the maximum Risk constraint applied.

22. Number of non-Load List items that had the minimum Risk constraint applied.

Effectiveness of Conventional Tender Load Lists

After all candidate items have been examined and the statistics collected, the Load List effectiveness can be evaluated. Once again, the computations differ for unit and requisition effectiveness. The computations also depend on whether we are looking at all items together or equipment-related and non-equipment-related items separately. Both gross and net effectiveness are computed even though the evaluation may be based on one or the other.

The Net Unit Effectiveness is:

Computing effectiveness

$$\text{Net Unit Effectiveness} = \frac{\left(\text{A Units Satisfied}\right)}{\left(\begin{array}{c}\text{Accumulated A Support}\\ \text{Period Load List Demand}\end{array}\right)}$$

where A will be ER and NER if item types are being considered separately and ER + NER if item types are being considered together.

The Gross Unit Effectiveness is:

$$\text{Gross Unit Effectiveness} = \frac{\left(\text{A Units Satisfied}\right)}{\left(\begin{array}{c}\text{Accumulated A Support}\\ \text{Period Load List Demand}\end{array}\right) + \left(\begin{array}{c}\text{Accumulated A Support}\\ \text{Period Non-Lead List}\\ \text{Demand}\end{array}\right)}$$

For Net and Gross Requisition Effectiveness, requisitions satisfied would be substituted for units satisfied and Support Period demand frequency would be substituted for Support Period demand.

The total dollar value of the Load List is also computed. It is the accumulated dollar value of the depth of each item. This dollar value is the Load List quantity for each item times its unit price (B053). A separate value is not computed for equipment-related and non-equipment-related items. The value computed is for both classes of items combined.

Depth Calculation for FBM Tenders

POS

As we mentioned earlier, the Load List quantities for FBM tenders make up the Peacetime Operating Stock (POS). The Quarterly Demand Forecast for FBM material is based on either the simple average of historical demand data or on the BRF-population information. There is no Range cut used in the preparation of FBM tender Load Lists.

The initial step in the computation of the depth is to modify the demand forecast and its standard deviation to reflect the tempo and the resupply period. The resupply period demand forecast is:

$$\bar{D}_{RP} = \begin{pmatrix}\text{Quarterly Demand}\\ \text{Forecast}\end{pmatrix} \times \begin{pmatrix}\text{POS Adjustment}\\ \text{Factor}\end{pmatrix} \times \begin{pmatrix}\text{Resupply}\\ \text{Period}\end{pmatrix}$$

where the POS Adjustment Factor, used to adjust the tempo of demand, and the Resupply Period are input parameters.

The standard deviation of the resupply period demand is:

$$\sigma_{RP} = \sigma \times \sqrt{\begin{pmatrix}\text{POS Adjustment}\\ \text{Factor}\end{pmatrix} \times \begin{pmatrix}\text{Resupply}\\ \text{Period}\end{pmatrix}}$$

where σ = standard deviation of quarterly demand computed earlier.

If the computed Quarterly Demand Forecast is greater than zero, the Acceptable Risk is computed:

Acceptable risk

$$\rho = \frac{\lambda CA}{\overline{D}_{RP}}$$

where λ = Risk parameter

C = Unit price (B053)

A = Average Requisition Size (=1 for BRF forecasts)

$\overline{D}_{RP}$ = Resupply Period Demand Forecast

If the demand forecast is zero, the Risk is set to its maximum permissible value (an input parameter).

The computed Acceptable Risk is compared to minimum and maximum limits; 0.01 and 0.99, respectively. If it is outside these limits, it is set to a minimum or maximum value (input parameters).

The conventional tender depth calculations used only the normal distribution. The FBM tender depth computation use the Poisson distribution if the Resupply Period Demand Forecast is one or less and the normal distribution if it is greater than one. The procedures followed are given in Appendix A.

Poisson and normal probability distributions

Since no range cut is used in the FBM tender procedures, the computed depth is rounded to the next highest integer if it is greater than zero and to zero if it is less than zero.

The depth is the subjected to the same series of checks and modifications described in the section dealing with conventional tender depth. They are:

1. Mandatory Quantity Override.
2. Exclusion Override.
3. Allowing only significant differences between the old depth and the new depth.
4. Minimum Quantity Override.
5. Extended Dollar Value must be $1.00 or greater.
6. Rounding to next highest multiple of the Minimum Replacement Unit (MRU).
7. Maximum Quantity Override.

In addition, if the item has no demand history and no override, the computed quantity is limited to 50 units (unless the MRU is greater than 50) and the Extended Dollar Value to $100.00.

Items whose Extended Dollar Value is greater than $100,000 will not be included on the Load List (unless overridden on) but will be output on an error listing for review.

Load List Statistics for FBM Tenders

After the Load List quantity has been found, the expected number of units short and requisitions short can be found using the mean and standard deviation of the Resupply Period

Demand, the Average Requisition Size, the Load List quantity, and the Poisson or normal distribution. The procedures are authorized in Appendix B.

Computing shorts and satisfieds

The FBM tender effectiveness is measured only in terms of requisitions satisfied. This means that the expected number of requisitions satisfied must be found

$$\begin{matrix}\text{Expected Number of}\\ \text{Requisition Satisfied}\end{matrix} \quad \left(\frac{\bar{D}_{RP}}{A}\right) - \left(\begin{matrix}\text{Expected Number of}\\ \text{Requisitions Short}\end{matrix}\right)$$

The quantity calculated can be no less than zero.

The expected number of requisitions satisfied is accumulated for all Load List items. The expected number of Resupply Period requisitions are accumulated for both Load List and non-Load List items.

Effectiveness of FBM Tender Load Lists

Just two effectiveness calculations are made for FBM tender Load Lists: Net Requisition Effectiveness and Gross Requisition Effectiveness. Unit effectiveness is not considered and no distinction is made between effectiveness for equipment-related and non-equipment-related items.

The Net Requisition Effectiveness is

Computing effectiveness

$$\text{Net Requisition Effectiveness} = \frac{\left(\text{Total Number of Requisitions Satisfied}\right)}{\left(\text{Total Number of Load List Requisitions}\right)}$$

and the Gross Requisition Effectiveness is

$$\text{Gross Requisiton Effectiveness} = \frac{\left(\text{Total Number of Requisitions Satisfied}\right)}{\left(\text{Total Number of Load List Requistions}\right) + \left(\text{Total Number of non-Load List Requisitions}\right)}$$

ADJUSTING THE RISK PARAMETER

Regardless of whether we are considering Conventional or FBM Tenders, unit or requisition effectiveness or dollar value, must have some means of determining when we have met our objective or objectives. We do this by comparing the value or values computed with our goal or goals and, if the computed value differs from the goal by too great a margin, we adjust the risk parameter and initiate another computation. This process continues until the deviation of the computed value from the goal meets some specified requirement.

If total dollar value or combined ER and NER effectiveness (either net or gross) is our measured value, we will have a single goal in terms of either total

dollar value or combined effectiveness. If the effectiveness of ER and NER items is being computed separately, we will have two goals — one for ER effectiveness and the other for NER effectiveness.

Effectiveness goal

If we are considering effectiveness and the computed value is much lower than our goal, this means that we have allowed too high a level of acceptable risk. To increase the effectiveness, we must reduce the acceptable level of risk. We do this by reducing the value of λ, the risk parameter. If you look back at the equations for acceptable risk, you will see that the larger λ is, the larger will be the acceptable risk, and, the smaller λ is, the smaller will be the acceptable risk.

The opposite is true. If the effectiveness is too high, we have set the acceptable level of risk too low. You might ask: How can effectiveness be too high? If we surpass our goal, aren't we that much better off? Well, the achievement of that increased effectiveness is at the expense of additional depth in our Load List. This additional depth costs money. So if we surpass our goal, we are expending funds that might be better utilized elsewhere.

So if effectiveness is too high, we can reduce it by increasing our acceptable level of risk. This is done by increasing the risk parameter.

Dollar value objective

A dollar value goal is met in the same way. If the dollar value is too high, we reduce it by decreasing the Load List depth. This is done by increasing the risk parameter which in turn increases the acceptable level of risk.

Three values of the risk parameter are input to the operation prior to the depth computations. (If ER and NER effectiveness are being considered separately, a total of six values, three for each type of item, will be input.) After the computations, the effectiveness or total dollar value are manually compared to the goal. If the goal has been met (within the specified tolerance band), no further computations are required. If the goal has not been met, three additional risk parameters are selected and the operation is rerun. This process continues until the goal has been achieved.

REVIEW AND SKIM LISTINGS

After the computed Load List is deemed satisfactory in terms of meeting the desired goal or goals, a series of listings are prepared for examination by SPCC and FMSO.

NIIN	IC	FSC	COG	NAME	UNIT PRICE	UN /I	NEW QTY	OLD QTY	ORDER QR	ORDER QTY	SHIP POP	TENDER POP	DMD FREQ	DMD QTY	BEST REP EPC	MRV	REV CODES 1 2 3 4 5	MIC
007708388		2040	1H	WEDGE	00001·50	EA	20	0		0	0	0	5	165	00·0000	1	A Q D	
007708389		2040	1H	WEDGE	00001·50	EA	19	0		0	0	0	5	163	00·0000	1	A Q D	
007717428		4720	1H	HOSE	00001·60	FT	90	90		0	840	0	2	86	02·0604	1	P Q D	97990001
007722004	CC	5910	1H	CIRCU	00074·00	EA	1	0		0	250	0	4	0	00·0091	1	A Q	92601290 92601290PA
007730253		5845	1H	AMPLI	00037·00	EA	0	1		0	36	0	3	0	00·0498	1	D	52240501
007732782		5950	1H	COIL	00022·50	EA	8	1		0	554	0	14	24	00·0155	1	I P Q D	NONE
007732786		5950	1H	COIL	00060·00	EA	7	1		0	436	0	2	25	00·0125	1	I P Q D	NONE
007732842		1355	1H	RETAI	00009·30	EA	7	0		0	0	120	20	0	00·0850	1	A Q D	0053F0009
007746600		4140	1H	FAN C	00176·00	EA	0	1		0	5	0	2	2	00·0853	1	D	28200009 28200009
007751359		1450	1H	PIN V	00000·23	EA	5	0		0	0	0	2	0	00·0000	1	A Q D	
007752561		4820	1H	VALVE	00031·50	EA	2	2		0	46	0	5	0	00·1150	2	Q D	NONE
007761627		5360	1H	SPRIN	00002·20	EA	7	7		0	7	0	11	0	00·7961	1	Q D	99010010
007761631		5360	1H	SPRIN	00001·20	EA	4	4		0	7	0	6	0	00·4395	1	Q	99C010010
007761640		5360	1H	SPRIN	00001·01	EA	5	5		0	7	0	6	0	00·4799	1	Q	99010010
007761655		5310	1H	WASHE	00208·00	EA	1	7		0	7	0	10	0	00·7642	1	M P Q D	99010010
007761658		5310	1H	WASHE	00000·24	EA	12	12		0	7	0	15	0	01·1386	1	Q D	99010010

EDITED CANDIDATE REVIEW RECORD
(E17MA1L)

Review Listings

Two of these listings are designated review listings and consist of the Edited Candidate Review Record (sometimes referred to as E17MA1L) and the Stock Number Sequence List (E17RC1L).

Edited Candidate Review Record

An example of the Edited Candidate Review Record is shown on the next page. Along with general item descriptive data, the new and old Load List quantities are printed as are the Override Code and the Override Quantity. The population is divided into ship installable and tender installable. The demand frequency, demand, Best Replacement Factor, and the Minimum Replacement Unit Quantity are printed next. This is followed by the Review Code.

The Review Code has five positions. The first position can be blank or any of four alphabetic characters:

Code	Meaning
D	The item has been deleted from the Load List. It did appear on the previous Load List.
A	The item has been added to the Load List. It did not appear on the previous Load List.
I	The new Load List quantity is greater than the previous Load List quantity.
M	The new Load List quantity is less than the previous Load List quantity.
Blank	The new Load List quantity equals the old Load List quantity.

The second position of the Review Code indicates a data void. If the Item Name (C004), Cog Symbol (C003), Unit of Issue (C005), or Unit Price (B053) are zero or blank, a "V" will be entered in the second position. Otherwise, it will be blank.

A "P" in the third position of the Review Code indicates that the extended price of the Load List quantity exceeds a input specified value. The extended price is the new Load List depth (E009) times the Unit Price (B053).

A "Q" in the fourth position of the Review Code means that the new Load List quantity (E009) exceeds an input specified value.

Finally, the fifth position of the Review Code will contain a "D" if the item's Quarterly Demand Forecast (E016C) exceeds an input specified value.

The Candidate Review Record also contains the Application Code (D009) that identifies a higher level item to which the subject item is related. Up to four Application Codes may be listed. This data area is labeled RIC since the Application Code is related to the Repairable Identification Code (D008).

AS II LOAD LIST SECT II 09-29-77

SM

CDE	STOCK NUMBER		IC	ITEM NAME	U/I	UNIT PRICE	W/CUBE	LOAD QTY	A	B	C	D	E	F	G
1H	1650	002532[illegible]		FILTER ELEMENT,FLUI	EA	112.10	.	1	1	U		0	00		M
9N	5965	002553701		RESISTOR,FIXED,COMP	EA	.12	.0010	9	1	U		0	00		
9G	8250	002554213		LAMPHOLDER	EA	1.63	.0080	8	1	U		0	00		
9G	3432	002559271		FLUX,SOLDERING	CN	.19	.0130	6	1	U		0	00		
9G	3439	00255[illegible]77		FLUX,WELDING	LB	.97	.0210	2	1	U	B	0	00	T	
9N	5603	0025[illegible]67		RESISTOR,FIXED,FILM	EA	.44	.0000	20	1	U		0	00		
9Q	6140	002553719		BATTERY,STORAGE	EA	13.80	.	8	4	U		0	00		
9Q	6140	002553721		BATTERY,STORAGE	EA	41.09	.	1	1	U		0	00		
1H	9905	002555729		HOLDER,CARD-LABEL	EA	7.30	.	1	1	U		0	00		M
1H	9905	002555730		HOLDER,CARD-LABEL	EA	7.80	.	1	1	U		0	00		M
1H	9905	002555731		HOLDER,CARD-LABEL	EA	5.90	.	1	1	U		0	00		M
1H	9905	002555733		HOLDER,CARD-LABEL	EA	57.00	.	1	1	U		0	00		M
1H	9905	002555734		HOLDER,CARD-LABEL	EA	21.50	.	1	1	U		0	00		M
9[illegible]	7330	002555915		PAN,BREAD	SE	21.94	.	1	1	U		0	00		
9Z	5330	002556479		GASKET	EA	.67	.0010	6	2	U		0	00		
9Z	5330	002556491		GASKET	EA	.03	.0000	34	1	U		0	00		
9Q	7920	002557336		BRUSH,CHASSIS AND H	EA	1.97	.	1	1	U		0	00		
9Q	3439	002557711		ELECTRODE,CUTTING,T	LB	1.42	.	1	1	U		0	00		
9Q	4140	002557798		FAN,CIRCULATING	EA	62.06	.0790	1	1	U		0	00		
9Q	4140	002557801		FAN,CIRCULATING	EA	61.32	1.5000	1	1	U		0	00		
9D	8415	002558577		APRON,FOOD HANDLERS	EA	.65	.	2	1	U		0	00		
9N	5961	002559075		TRANSISTOR	EA	15.00	.0000	4	1	U		0	00		
9Q	4130	002559[illegible]		RING,PISTON	EA	.58	.0320	9	3	U		0	00		
9Q	4130	002559112		RING,PISTON	EA	.51	.0500	6	6	U		0	00		
9Q	4130	002559114		RING,PISTON	EA	2.19	.0100	4	2	U		0	00		
9Q	6685	002559516		TEMPERATURE INDICAT	EA	2.65	.	1	1	U		0	00		
9N	5960	00256[illegible]01		ELECTRON TUBE	EA	7.75	.3030	3	1	U		0	00		
9Z	5330	002563159		PACKING,PREFORMED	EA	.15	.0010	56	2	U		S	00		
9Z	5330	002563103		PACKING,PREFORMED	EA	.10	.1000	48	3	U		S	00		
9Z	5330	002563105		PACKING,PREFORMED	EA	.09	.0210	42	1	U		S	00		

PRELIMINARY LOAD LIST
(E17RC1L)

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NIIN	SMIC	FSC	COG	NAME	CONTROL	PRICE	U/I	MFM	OLD	OR QTY	S-POP	T-POP	FREQ	DMD QTY	RIC
006632636		6505	9L	SODIUM CHL	00000051	00000007	PG	00051	00000	00000	000000	000000	00003	000080	
009135476		5310	9Z	NUT,PLAIN,	00000051	00000043	EA	00051	00000	00000	000034	000000	00002	000086	0A0070001
009244083		6505	9L	ATROPINE I	00000051	00000102	EA	00051	03A80	00000	000000	000000	00002	000200	
000435014		5330	9Z	PACKING,PR	00000052	00000074	EA	00052	00004	00000	000729	000000	0000A	000089	241430001
001522911		5940	9G	TERMINAL,L	00000052	00000024	EA	00052	00023	00000	000000	000000	00002	000100	
002730428		2815	3C	RING,PISTO	00000052	00000090	EA	00052	00000	00000	000096	000000	00006	000090	665710046
004849304	K3	5340	1H	ANODE,CORR	00000052	00000520	EA	00052	00000	00000	000008	000000	00009	000119	036040006
008404161		5330	9Z	PACKING,PR	00000052	00000007	EA	00052	00000	00000	002000	000000	00010	000129	
006632151		5330	9Z	RETAINER,P	00000052	00000013	EA	00052	00027	00000	000311	000000	00009	000084	MORF
007526727		5330	9Z	PACKING,PR	00000052	00000009	EA	00052	00000	00000	000108	000000	00014	000138	006340001
008176296		5360	9Z	SPRING,HEL	00000052	00000066	EA	00052	00016	00000	000392	000000	00001	000080	MORF
008391846		5330	9Z	RETAINER,P	00000052	00000004	EA	00052	00012	00000	000430	000008	00094	000000	MORF
004743718		6685	1H	FILTER,ULT	00000052	00000200	EA	00052	00112	00000	000078	000000	00011	000178	384860009
004777260		5999	9N	CONTACT,ELL	00000052	00000010	EA	00052	00026	00000	002582	000000	00002	000058	MORF
009655581		6640	9L	PAPER,FILT	00000052	00012?0	RC	00052	00004	00000	000029	000000	00034	000172	69008100
000130472		3655	9G	SLEEVE, CE	00000053	00000173	EA	00053	00005	00000	000512	000000	00002	000064	169140002
000976402		5310	9Z	WASHER,FLA	00000053	00000209	EA	00053	00003	00000	000512	000000	00002	000064	169140002
002022559		5330	9Z	PACKING AS	00000053	00000036	AY	00053	00000	00000	000000	000000	00004	000118	

QUANTITY SKIM

NIIN	SMIC	FSC	COG	NAME	CONTROL	PRICE	U/I	NEW	OLD	DR QTY	S-POP	T-POP	FREQ-DMD	QTY	RIC
004613224		5340	9Z	SHIM	00000001	00000010	EA	00020	00000	00000	001350	000000	00041	000000	00511019A
004363525		5905	9H	RESISTOR,V	00000002	00000520	EA	00010	00001	00000	000024	000000	00042	000000	195110004
004783213		5961	9Y	SEMICONDUC	00000002	00000211	EA	00001	00049	00000	000012	000000	00042	000000	2A2E5P011
004977437		5945	9H	RELAY,ARMA	00000002	00001073	EA	00003	00000	00000	000024	000000	00042	000000	195110004
005172061		1220	1H	HOUSING,SH	00000002	00000024	EA	00007	00000	00000	000045	000000	00042	000000	005120001
005190418		2310	9Z	NUT,SELF-L	00000002	00000007	EA	00033	00000	00000	000135	000000	00042	000000	005110194
LLMQUE13A	CPM2	1055	2M	PRJNE,LIOU	00000003	00012500	EA	00001	00000	00000	000120	000000	00043	000000	169140002
LLN513502		4022	1H	PACKING,PREFO	00000003	00000500	EA	00010	00000	00000	000032	000000	00043	000000	005110024
004271911		5910	9Y	CAPACITOR,	00000003	00000087	EA	00033	00011	00000	002550	000101	00043	000000	400C
002611129	X1	4820	1H	DIAPHRAGM,	00000003	00001950	EA	00004	00060	00000	000064	000000	00043	000000	1H7U20UCA
004311131		4730	9C	TEE,PIPE	00000003	00000215	EA	00031	00022	00000	000004	004530	00043	000000	090E60002
004254203		5340	9Z	LOCKING PL	00000003	00000017	EA	00006	00000	00000	000032	000000	00043	000000	140020010
006363754		5905	9Y	RESISTOR,V	00000003	00001000	EA	00006	00012	06000	000020	000000	00043	000000	195110004
004821772		7920	9Q	TOWEL,PAPE	00000003	00007205	BX	00071	00001	00000	000000	000000	00043	000419	
007691062		2915	2G	SEPARATOR,	00000033	00000221	EA	00027	00001	00000	000048	000000	00043	000000	990030021
010133540		5310	9Z	RETAINER,P	00000003	00000420	EA	00012	00000	00000	000032	000000	00043	000000	520170080
010133623		5310	9Z		00000003	00000369	EA	00012	00000	00000	000032	000000	00043	000000	520170080

DEMAND FREQUENCY SKIM

77131 EXTENDED PRICE PAGE 240

NIIN	SMIC	FSC	COG	NAME	CONTROL	PRICE	U/I	NEW	OLD	OR	QTY	S-POP	T-POP	FREQ-DMD	QTY	RIC
000097920		7920	9Q	BRUSH,VARN	00000526	00000013	EA	00016	00024		00000	000000	000000	00020	000075	
000922571		5330	9Z	PACKING,PR	00000526	00000084	EA	00006	00006		00000	000044	000000	00003	000004	616370049
001874249		5350	9Q	CLOTH,ABRA	00000530	00000530	RO	00001	00000		00000	000000	000000	00002	000020	
002302397		5130	9Q	CHISEL,PUN	00000530	00000530	EA	00001	00000		00000	000000	000000	00003	000006	
002370574		5210	9Q	GAGE,MARKI	00000530	00000530	EA	00001	00000		00000	000000	000000	00003	000005	
002433787		5920	9Q	FUSE,CARTR	00000530	00000010	EA	00053	00053		00000	004469	000000	00004	000094	NORF
002827949		6685	9Q	THERMOMETE	00000530	00000530	EA	00001	00001		00000	000000	000000	00003	000005	
004758377	X3	9535	1H	WIRE,MONEL	00000530	00000530	RO	00001	00001	CS	00001	000025	000000	00002	000003	NORF
005522421		2995	1H	RESISTOR,A	00000530	00000510	EA	00001	00000		00000	000012	000000	00003	000004	820210006
008163819		4240	9Q	GOGGLES,IN	00000530	00000530	PR	00001	00000		00000	000000	000000	00003	000005	
008922555	1	5330	9Z	PACKING,PR	00000530	00000100	EA	00005	00000		00000	000010	000000	00007	000000	520290001
009016729		5330	9Z	GASKET	00000530	00000530	EA	00001	00001		00000	000008	000000	00004	000000	886335120
009264146	L1	4710	1H	TUBE,METAL	00000530	00000530	FT	00001	00000		00000	000000	000000	00003	000035	
001740970		9390	9Q	WICK	00000531	00000177	HD	00003	00000		00000	000201	000000	00004	000000	NORF
002633374		8020	9Q	BRUSH,PAIN	00000532	00000016	EA	00007	00025		00000	000000	000000	00012	000071	
002773375		4210	9C	NIPPLE,HOS	00000532	00000532	EA	00001	00001		00000	000000	000000	00004	000019	
005011058		4925	1H	CAP,SPLICE	00000532	00000420	EA	00019	00050		00000	000000	000000	00002	000060	
005762825		5360	9Z	SPRING,HLL	00000532	00000019	EA	00028	00000		00000	000000	012000	00052	000000	006300009

PRICE SKIM

77131 SKIP QUANTITY BY FSN PAG 81

NIIN	SMIC	FSC	COG	NAME	CONTROL	PRICE	U/I	NEW	OLD	OR QTY	S-POP	T-POP	FREQ	DMD QTY	MIC
009741732		4330	9C	FILTER ELE	00000000	00000090	EA	00003	00001	00000	000000	000000	00002	000011	
009830993		4330	9C	FILTER ELE	00003000	00000610	EA	00008	00000	00000	000004	000000	00001	000012	4R0120080
010031251		4330	9C	FILTER ELE	00000000	00000300	EA	00006	00000	00000	000007	000000	00013	000000	4R0050002
010121592		4330	9C		00000000	00051370	EA	00001	00000	00000	000009	000000	00005	000000	4R0060247
010198339	2	4330	1H	FILTER,ELE	00000000	00000250	EA	00000	00000	00000	000004	000000	00015	000000	4R0060593
005863601		4410	1H	HEATER CUI	00000000	00003350	EA	00005	00005	00000	000130	000000	00004	000025	070670007
000021163		4420	1H	PLUG,PERMA	00000000	00004700	EA	00001	00001	00000	000000	001552	00300	000000	040000092
000021166		4420	1H	PLUG,PERMA	00000000	00001600	EA	00003	00000	00000	000000	007774	01604	000000	04020001
000021167		4420	1H	PLUG,PERMA	00000000	00001350	EA	00004	00001	00000	000000	000672	00073	000000	040260003
003030135		4420	1H	GASKET,COV	00000000	00000240	EA	00006	00000	00000	000024	000000	00001	000008	030000081
003030154		4420	1H	GASKET,ZIN	00000000	00000050	EA	00008	00000	00000	000016	000000	00001	000008	030000067
006504670		4420	1H	JET PIPE A	00000000	00022100	EA	00001	00000	00000	000021	000000	00006	000000	616930001
006504671		4420	1H	LANGE DIAP	00000000	00004400	EA	00001	00001	00000	000021	000000	00003	000004	616930001
006504673		4420	1H	JEWEL DEAR	00000000	00002500	EA	00001	00000	00000	000021	000000	00005	000000	616930001
009204252	43	4420	1H	LOCKING DE	00000000	00000140	EA	00009	00005	00000	000048	000000	00001	000011	016490001
001421037		4430	9C	CANTRIDGE,	00000000	00000652	EA	00018	00006	00000	000005	000000	00017	000047	325000002
001421030		4440	9C	CANTRIDGE,	00000000	00001695	EA	00001	00062	00000	000000	000000	00010	000037	
004752624		4440	9C	CANTRIDGE,	00000000	00002922	EA	00001	00001	00000	000008	000009	00005	000000	325000124

NSN SEQUENCE SKIM

The second review listing shows the reviewer what the Load List would lock like if no changes are made. An example from this listing is shown on page 6-34.

SKIM Listings

The SKIM listings essentially present the Load List data in several different formats to enable the analyst to more easily make decisions relative to the further elimination of items from the Load List.

There are four SKIM Lists and the basic format for the four is the same. Examples of the four lists are shown on pages 6-35 through 6-38. The first, the Quantity SKIM, lists the items of the Load List in ascending quantity. The lowest quantity item is listed first and the highest quantity item last.

The second SKIM is a printing of Demand Frequency, again in low to high sequence. The Price SKIM lists the items by extended price from low to high. The fourth SKIM is the NSN Sequence listing the NIINs in quantity sequence, from low to high.

Master Candidate Load List

This tape is produced at the same time as the review and SKIM listings and become the Master file for the Load List.

After SPCC's Allowance Division and FMSO's Load List Branch have analyzed the review and SKIM listings, FMSO incorporates any changes into the Master Candidate Load List File via files maintenance procedures. These changes are referred to as "post model" changes.

Financial statistics concerning the Load List are forwarded to NAVSUP for approval. When approval is received, the final Load List outputs can be prepared.

FINAL LOAD LIST OUTPUTS

SMAR

As with the FIRL/FILL operation, the TARSLL operation produces two distinct final outputs. The first of this is the file, either on tape or cards, of the Supply/Management Aid Records. As we have mentioned several times, these SMARs are used by the Mobile Logistics Support Force in managing its items. A nomenclature (item name) tape is also prepared.

The second final output is the Load List publication itself. Unlike the single publication (CARGO) resulting from the FIRL/FILL operation, there will be a number of different published Load Lists produced by the TARSLL operation. There wi. e one for Destroyer Tenders, Repair Ships, (these first two have been combined recently), non-FBM Submarine Tenders, and Submarine Tenders.

The contents of these publications result solely from the FMSO Load List operations. There are no chapters submitted by other agencies.

THE WEAPON SYSTEM SUPPLEMENT

The Strategic Systems Support Division of SPCC has the responsibility for determining the Load List quantities for the Weapon Systems Supplement. This addition to the FBM Tender Load List is prepared to support Strategic Systems Project Office equipments. The UICP mechanized procedures are not followed for these equipments since, for much of the material of interest, the contractor serves as inventory manager. (These are the "P" Cog items.)

The procedures follow the PMP discussed earlier in this chapter. Once the hull mix for the load is designated by the TYCOM, the contractor receive a copy of it and prepare range and depth information for the items associated with

their equipments. For contractor-managed items, the quantities are firm. Contractors may also recommend quantities for items other than those they manage. These recommended quantities are not firm. The range and depth information is supplied by the contractors on punched cards which are transferred to magnetic tape.

The Strategic Systems Support Division uses the hull mix to interrogate their Master Configuration File (equipments - APL designators) and Component Data File (parts) to produce the candidate file (CZ1). The contractor range and depth file is matched to the candidate file. A mismatch listing may be produced in which case a manual review is required.

Contractor-managed ("P" Cog) items are assigned mandatory overrides and items from other cogs are assigned either maximum quantity or minimum quantity overrides (the determination of which to use is determined by the Project Office).

These candidates with overrides enter the UICP processing and produce SKIM and Review listings. These listings are examined by SSSD personnel and post-model changes, if necessary, are prepared.

VII

SUPPLY/MANAGEMENT AIDS REVISION

The Supply/Management Aid Records (SMARs) for both FIRL/FILL and TARSLL Load Lists may be updated at times other than the scheduled revision times. This allows FMSO to meet requests for management and financial information with the most current data.

The SMARs from any number of Load Activity Codes may be revised at one time. However, Load Activity Codes will be grouped in tens and the revision done for each group separately. The SMARs to be revised may be entered into the process either on the magnetic tapes as generated by the FIRL/FILL and/or TARSLL process or on cards.

The SMARs from the various sources are merged and sorted by NIIN and by LAC within each NIIN.

Any SMAR which represents a Range Delete will be ignored and will not be revised. Referring to the example SMAR given on page 7-2, you can see that a range delete is indicated by a "3" in Position 3. Any records not identified as Load List, Load List Supplement, or SSPO Weapon System Supplement are dropped from the process.

EXAMPLE OF A SMAR RECORD

```
         11111111112222222222333333333344444444445555555555666666666677777777778
12345678901234567890123456789012345678901234567890123456789012345678901234567890
G15 M 5930006239571  EA  000 FILLA U   0000300001  1H00001  0000000 0 0002300
G14 M 5360006243260  EA  000 FILLA U   0000000000  1H00001  0000000 0 0000230
G15 D 61050C6243997TMEA  000 FILLA U   0000300002  1H00002  0000000 0 0C18000
G15 M 4320006253848  EA  000 FILLA U   0000100001  1H00001  0000000 0 0045000
G15 M 5930006254652  EA  000 FILLA U   0000100001  1H00001  0000000 0 0014100
G15 M 1440006254723  EA  000 FILLA U   0000100001  1H00001  0000000 0 0001200
G14 MS5845006264404  CN  000 FILLAGU   0000700001  1H00001  0000127 0 0000180
G11 M 6605006289180  AY  000 FILLA U   0000100001 M1H00001  0000000 0 0006100
```

Col.	Data
1-3	Document Identifier
1	Type Requirement List
2	Type Item Ident. No.
3	Action Code
4	Load List Special Handling Code (F)
5	Choice of Items Code (T)
6	Material Control Code
7	Special Material Content Code
8-20	NSN/ACN
21-22	Special Material Ident. Code
23-24	Unit of Issue
25	Credit Code
26	Equipage/Equipment Categorization & Custody Code (T)
27	Shelf Life Code
28-29	Shelf Life Action Code
30	Service Designation Code (T)
31-35	Load Activity Code
36	Type of Storage Space Code
37	Security Code
38-41	Relative Item Essentiality (T)
42-46	Load List Requisitioning Objective Quantity (F)
47-51	Load List Reorder Point (F)
52-53	Blank
54	Migration Code (FF)
55-56	Cog Symbol
57-61	Load List Quantity
62	Insurance Item Code (T)
63	Demilitarization Code
64-70	Net Unit Cube
71	Blank or "D" (FF)
72	Unit Price Code
73	Selector Code (FF)
74-80	Unit Price

(F) FILL only

(FF) FIRL/FILL only

(T) TARSLL only

UPDATING TO THE CURRENT NIIN

The first step in the revision process is to ensure that each SMAR contains the most recent National Item Identification Number. This is done by comparing the NIIN on each SMAR to the old NIIN list of the Navy Management Data Addendum File. If a match is found, the current NIIN will replace the NIIN on the SMAR and a "CH" will be placed in Positions 52 and 53 of the SMAR to flag the NIIN change. A NIIN Cross Reference Card will also be generated.

UPDATING MANAGEMENT DATA

Each SMAR is also processed against the Navy Management Data File and various data elements are updated. These are:

DEN	DATA ELEMENTS
B053	Unit Price
B054	Unit Price Code (whether or not Unit Price is standard)
C003	Cognizance Symbol
C003A	Material Control Code
C003B	Special Material Control Code (SMIC)
C005	Unit of Issue
C017	Security Classification Code

DEN	DATA ELEMENTS
C024A	Net Cube (volume in cubic feet)
C027	Type of Storage Space Code
C028	Shelf Life Code
C029	Shelf Life Action Code
C042	Federal Supply Classification
D015	Special Material Content Code

Converting unit of issue

If the Units of Issue on the SMAR and the NMDF do not agree, the old (SMAR) Unit of Issue and new (NMDF) Unit of Issue are used as entries into the U/I Conversion Table in order to adjust the quantity as well as correct the Unit of Issue. The Load List quantity from the SMAR will be factored by the Conversion Table value. For example, if the SMAR Unit of Issue is DZ (dozen) and the NMDF Unit of Issue is EA (each), the conversion factor would be 12. The SMAR quantity would be multiplied by 12.

The Load List quantity cannot be revised to a value less than one.

If the two Units of Issue cannot be related in the U/I Conversion Table, the SMAR will be printed on an Error/Review List. SMARs that cannot be matched to the NMDF will also be printed on the Error/Review List.

The SMARs that have been rejected on the Error/Review List are reviewed by FMSO, Code 911, where the necessary

corrections are made. The corrections are prepared in the SMAR format and contain one of three possible Action Codes: A - Add a SMAR to a Load List; C - Change a SMAR for a Load List; or D - Delete a SMAR from a Load List.

If the Action Code is "D," any SMAR matching the NIIN and LAC on the correction card will be deleted from the process. If the Action Code is "C," one or more data fields on the SMAR will be replaced by the corresponding data fields on the correction card. Any data fields that are not to be changed must be blank on the correction card.

If the Action Code is "A," a new SMAR will be created for the NIIN/LAC if one does not currently exist. The quantity will be the quantity on the correction card. If a SMAR for the NIIN/LAC already exists, the quantity on an "A" correction card will be added to the existing quantity.

CONSOLIDATION OF SMARs

Combining SMARs

All SMARs that have the same NIIN/LAC will be consolidated into a single SMAR. The quantity on this single SMAR will be the sum of the quantities from the SMARs that have been consolidated. A consolidated SMAR will be coded "CN" in Positions 52 and 53.

More than one SMAR with the same NIIN/LAC will result in those instances where a NIIN has been updated to a current NIIN and a SMAR already exists for the current NIIN.

REVISED SMARs

A tape of each Load List will be generated after the updating, revision, and correction processes are completed. These revised SMARs will be sequenced by NIIN and a separate tape is prepared for each LAC.

Statistics

Statistics will be generated for each LAC once the revisions are made. Range and total extended dollar values are printed for each Cog, for all Cogs, for all Retail Cogs, for Navy Stock Account, and for Appropriation Purchase Account.

The same statistics may be produced for Item Managers: FMSO, SPCC, SPO, ASO, or other.

An optional output, which is usually provided, is the NIIN Commonality List. This is a listing by NIIN spread over all loads. This listing shows which loads carry each NIIN.

VIII

LOAD LIST EVALUATION

The UICP Load List procedures include an operation that permits the evaluation of the Load Lists that have been constructed. This evaluation can take place at any time after a Load List has been built and permits an evaluation using demands that have occurred subsequent to the time of construction.

Frequency and quantity effectiveness

The evaluation is performed in terms of frequency and quantity effectiveness. Frequency effectiveness compares the number of numbers of requisitions satisfied to the total number of requisitions submitted. Quantity effectiveness compares the quantity satisfied to the quantity demanded.

The evaluation procedure uses actual demand over a selected time period. This actual demand is then multiplied by a PWRS Factor that reflects the tempo of operations that are of interest in the evaluation.

Although this operation will be used primarily to evaluate a Fleet Issue Requirements List (FIRL) or a Fleet Issue Loads List (FILL), the capability exists to evaluate any Load List, given its LAC and the Unit Identification Codes (UICs) of the activities associated with the load.

THE DEMAND DATA

The demand data required for the evaluation can be drawn from two sources: the Mobile Logistics Support Force Master Demand File and the Unmatched NIIN Demand File. The use of the second source is optional. The MLSF Master Demand File contains the most recent 24 months of MLSF demand. The Unmatched NIIN Demand File contains the previous 24 months MLSF demand that was unmatched to the Load List Stock Number File.

Extracting demand data

The demand data can be extracted from these files in three different ways. First, FIRL/FILL demand can be requested and all demand coded as FIRL/FILL applicable to both Atlantic and Pacific loads will be extracted from the MLSF Master Demand File and, if desired, the Unmatched NIIN Demand File.

The second way of extracting demand data is by Reporter UIC.

The final method of extracting demand data is by Requestor UIC.

The extracted demand data will cover the full 24 months of available history and will not be tied to a

specific load. Since we are interested only in a specific time frame and a specific Load List, all demand falling outside the desired time period and not coded with the proper Load Activity Code will be eliminated from further consideration.

Applying the PWRS Factor

After the demand has been confined to the time period and LAC of interest, it is factored by the PWRS Factor to reflect the tempo desired in the evaluation period. The PWRS Factor is an input value and need not be the Fleet Support Factor that had been used in computing the load. Only the Demand Quantity is multiplied by the PWRS Factor.

THE LOAD LIST AND CANDIDATE DATA

Three demand categories

There are three demand classifications that are of interest to the evaluation process. The first is the demand for items that are on the Load List. The second is the demand for items that are not on the Load List but were considered candidates at the time the Load List was constructed. Finally, we would like to have some reporting, for manual review, of those items that were not included as candidates at the time the load was built but did experience significant demand during the time period selected for the evaluation.

In order to divide the extracted demand into the three

required categories, it is necessary to compare the demand records to the items on the Load List file and to the items on the candidate file.

Before the candidate file can be used in the evaluation, it must be updated as some period of time may have passed since the load was constructed and some of the candidate NIINs may be outdated. This updating is done by comparing the candidate file to the NMDF Addendum File. This latter file is a cross-reference of Old NIIN to Current NIIN. The candidate file will reflect the most current NIIN after the updating and will be compatible to the demand file whose NIINs are updated monthly.

The Load List data will be contained on a file consisting of the updated Supply Management Aid Records (SMARs) for the load being evaluated. If we are evaluating a FIRL, two files will be necessary, one for the FIRL (FIRLA, for example) and one for the associated FILL (FILLA).

CLASSIFYING THE DEMAND

The dividing of the demand into the three categories now becomes the process of comparing the sets of files.

The demand file is compared to the Load List file and, if a match is found, the item's identification, demand

quantity, and demand frequency as well as other management data are recorded on the Matched Load List/Demand File.

Matched demand

If the item from the demand file is not on the Load List file but is on the candidate file, the item information is saved on the Matched Candidate/Demand File.

Unmatched demand

The relevant item information will be recorded on the Unmatched Demand File if no match can be found on either the Load List or Candidate files.

At the same time the demand classification process is taking place, an accumulation of the quantities and frequencies for all items, whether matched or unmatched, is being made. These values will be later used in determining Gross Effectiveness.

Special note is also being taken of the Override Codes (particularly Mandatory and Minimum Quantity) associated with the items. One of the optional reports we can obtain from the evaluation operation is the effectiveness of the override actions.

LOAD LIST EFFECTIVENESS

The computation of the Load List effectiveness uses the demand classifications we have just discussed, in particular,

the demand for Load List items. We are going to measure effectiveness in both the net (how well we meet the demand for Load List items) and the gross (how well we meet the demand for all items) sense. We are also going to measure frequency (how many requisitions we satisfy) and quantity (how many units we satisfy) effectiveness.

We have already talked several times in this manual about how effectiveness is calculated. Net Effectiveness is very simply

Computing Net Effectiveness

$$\text{Net Effectiveness} = \frac{\text{Demand Satisfied}}{\text{Demand Received (matched to Load List)}}$$

Demand Satisfied will be the number of requisitions filled, if we are talking of Frequency Effectiveness, and the number of units issued if we are talking of Quantity Effectiveness. Demand Received will either be the total number of requisitions for Load List items or the total quantity of Load List material requested.

The effectiveness is measured in terms of the totals for all items. As these values are being accumulated, there may have to be some adjustments to the values computed for individual items. For an item, three possible situations might arise.

DEMAND QUANTITY GREATER THAN LOAD LIST QUANTITY

In this case, the number of satisfied requisitions must be computed.

$$\text{Satisfied Requisitions} = \frac{\text{Load List Quantity}}{\text{Demand Quantity}} \times \text{Demand Frequency}$$

The other necessary evaluation factors are:

- Unsatisfied (NIS) Requisitions = Demand Frequency - Satisfied Requisitions
-
- Satisfied Quantity = Load List Quantity
- Unsatisfied (NIS) Quantity = Demand Quantity - Load List Quantity
- Excess Quantity = 0
- Excess Value = 0

DEMAND QUANTITY LESS THAN LOAD LIST QUANTITY

Here the evaluation factors are found as follows:

- Satisfied Requisitions = Demand Frequency

- Unsatisfied Requisitions = 0
- Satisfied Quantity = Demand Quantity
- Unsatisfied Quantity = 0
- Excess Quantity = Load List Quantity - Demand Quantity
- Excess Value = Excess Quantity x Unit Price

DEMAND QUANTITY EQUALS LOAD LIST QUANTITY

In this final case,

- Satisfied Requisitions = Demand Frequency
- Satisfied Quantity = Demand Quantity

The other effectiveness measure is Gross Effectiveness where:

Computing Gross Effectiveness

$$\text{Gross Effectiveness} = \frac{\text{Demand Satisfied}}{\text{Demand Received (matched and unmatched)}}$$

Gross Effectiveness uses the Satisfied Requisitions or Satisfied Quantity computed above in its numerator. In the denominator, all demand received is considered whether matched to the Load List or not.

An example page for a Load List Demand Effectiveness Report is shown on the next page. If a FIRL is being evaluated, there will be two reports, one for FILL and one for FIRL Only.

As can be seen, the items are ranked in terms of demand frequency. This permits the reviewer to concentrate on those items with high demand frequencies, those items that have the greatest impact on effectiveness.

OPTIONAL REPORTS

A member of optional reports may be produced in addition to the effectiveness reports we have just discussed. As with the effectiveness reports, if we are evaluating a FIRL, there will be two versions of each optional report; one for FILL and one for FIRL Only.

Override Effectiveness

Override Effectiveness

This report is similar in format to the standard effectiveness except now the Override Code is included. The only two Override Codes of interest are the "add" overrides: Mandatory Quantity and Minimum Quantity. A review of this report permits an evaluation of our override policy regarding specific items.

FIMLP LOAD LIST DEMAND EFFECTIVENESS TIMEFRAME 7608 THRU 7610 PWRS FCTR 1.000 PAGE 800

NSN		COG		DEMANDS		UNIT	LOAD	DMDS SATISFIED		DMDS NOT-IN-STK		LOAD EXCESS	
FSC	FIIN			FREQ	QTY	PRICE	QTY	FREQ	QTY	FREQ	QTY	QTY	VALUE
5310	00 167 1284	9Z		4	10	4.49	15	4	10			5	22
5340	00 182 5422	9Z		4	62	12.05	2	1	2	3	60		
4730	00 278 0682	9C		4	234	.06	20	1	20	3	214		
5365	00 287 0093	9Z		4	35	.32	14	2	14	2	21		
4330	00 287 4993	9C	E	4	72	1.11	39	3	39	1	33		
5315	00 298 1498	9Z		4	6	.54	1	1	1	3	5		
6620	00 415 2768	9F	E	4	4	532.19	12	4	4			8	4258
5999	00 504 9767	9N	E	4	7	13.27	1	1	1	3	6		
5330	00 542 1457	9Z		4	56	.06	64	4	56			8	1
5340	00 543 4394	9Z		4	47	.02	259	4	47			212	4
5330	00 579 7545	9Z		4	43	.12	26	3	26	1	17		
2815	00 587 3399	9C	E	4	8	264.16	1	1	1	3	7		
5310	00 595 7078	9Z		4	296	.03	204	3	204	1	92		
4320	00 600 1830	9C	E	4	19	9.39	1	1	1	3	18		
5305	00 637 9115	9Z		4	519	.01	1663	4	519			1144	11
5305	00 637 9277	9Z		4	350	.03	649	4	350			299	9

LOAD LIST EFFECTIVENESS REPORT

An example of an Override Effectiveness Report is shown on the next page.

Demand Value Stratification

In this optional report, the demand is categorized by range of unit price. As you can see in the example on page 8-13, the sequence of the report is by demand frequency. For each demand frequency, the number of items falling in each price category is shown along with the total quantity of these items' demand, and the extended price of the demand. Totals for the load are also shown.

Load List Value Stratification

This report is concerned with the total number of Load List items that occur in each price category and the total quantity and extended price in each quantity. An example is shown on page 8-14.

Projected Frequency Stratification

The Projected Frequency Stratification report tabulates Load List items, demand items, and demand frequency for each projected frequency range. The demand frequency and frequency effectiveness are also printed on a cumulative basis. See page 8-15 for a sample of this report.

FIRLA OVERRIDE EFFECTIVENESS   TIMEFRAME 7702 THRU 7704   PHAS FCTR 1.000   PAGE 13

ORIDE CCOB	FSC	NSN NIIN	COG	DEMANDS FREQ	DEMANDS QTY	UNIT PRICE	LOAD QTY	DMDS SATISFIED FREQ	DMDS SATISFIED QTY	DMDS NOT-IN-STK FREQ	DMDS NOT-IN-STK QTY	LOAD EXCESS QTY	LOAD EXCESS VALUE
XY	1615	00 956 5024	2R			1700.00	1					1	1700
XY	6515	00 963 5349	9L			3.12	1					1	3
XY	6750	00 965 4688	9G			27.93	1					1	28
XY	7530	00 972 8850	9G			176.55	1					1	177
XY	6810	00 985 7093	1H			2.50	1					1	3
XY	1560	00 991 8996	1R			1.40	1					1	1
XY	1430	00 997 2074	9I			47.55	1					1	48
XY	8465	01 012 3500	9D			10.00	1					1	10
XY	5335	00 110 5038	9Z	1	1	4.30	1	1	1				
XY	4030	00 132 9163	9Z	1	575	.05	3314	1	575			2739	137
XY	8430	00 144 1826	9D	1	18	3.15	1	1	1		17		
XY	5307	00 254 0802	9Z	1	9	.61	1473	1	9			1464	893
XY	4720	00 289 0756	1H	1	4	463.00	1	1	1		3		
XY	8405	00 421 2304	9D	1	24	3.02	1	1	1		23		
XY	4710	00 595 1927	1H	1	149	2.10	680	1	149			531	1115
XY	1650	00 716 1865	1R	1	1	41.00	1	1	1				
XY	9310	00 223 0372	9D	2	4	5.61	1	1	1	1	3		
XY	9520	00 277 5988	9Z	2	2012	.16	3369	2	2012			1357	217
XY	9535	00 277 7426	9Z	2	2	294.25	1	1	1	1	1		
XY	4710	00 289 0635	9C	2	2	4.20	1	1	1	1	1		
XY	5330	00 811 3229	9Z	2	16	.34	1	1	1	1	15		
XY	1560	00 514 1842	1R	4	4	35.00	1	1	1	3	3		
XY	8430	00 624 3249	9D	7	7	25.70	1	1	1	6	6		

ORIDE TOTALS 29 2,830 103,807 16 2,756 13 74 101,051 229
TOTL FIINS 329 SAT 6 NIS 9 XS 308 NET EFFECTIVENESS - FREQ 55.172 QTY 97,385

LOAD TOTALS 32 2,985 295,400 19 2,910 13 75 292,490 7,141
TOTL FIINS 2,240 SAT 8 NIS 162 XS 2,070 NET EFFECTIVENESS - FREQ 59.375 QTY 97.487
FLEET NET ORIDE EFFECTIVENESS -FREQ 79.144 QTY 77.418

FILL Ø DEMAND VALUE STRATIFICATION TIMEFRAME 7608 THRU 7610 PWRS FCTR 1.000 PAGE 2

UMU FREQ	J/P RANGE .00	.01 TO .10	.11 TO .50	.51 TO 1.00	1.01 TO 3.00	3.01 TO 10.00	10.01 TO 50.00	50.01 TO 500.00	OVER 500.00		FREQ RANGE TOTALS
13		6	9	11	22	12	15	1		NIINS	76
		6796	14287	3803	9192	2695	1225	21		UNITS	38,019
		224	5274	3054	13875	13922	26556	3948		EXT PRICE	67,853
14		3	14	13	22	9	11	2		NIINS	74
		728	2135	5393	7809	1137	1313	49		UNITS	25,764
		56	2906	3690	10485	5312	27977	4786		EXT PRICE	55,212
15		5	4	5	12	8	9	2		NIINS	45
		8215	3658	2462	6414	1958	595	36		UNITS	23,338
		280	892	1607	14089	11245	12284	5510		EXT PRICE	45,907
16		3	4	4	8	11	7	5		NIINS	42
		1891	7894	2289	3480	2696	766	275		UNITS	19,241
		61	2235	1762	6206	14789	14596	21167		EXT PRICE	60,816
17		2	9	6	9	7	8			NIINS	41
		946	11094	5812	5494	1570	1229			UNITS	26,145
		35	2314	3692	7852	6987	34156			EXT PRICE	55,036
18		3	5	5	5	2	7	1		NIINS	28
		1015	1797	2094	978	216	809	27		UNITS	6,756
		60	538	1406	1854	1997	11989	1936		EXT PRICE	19,780
19		1	1	3	4	5	5	1		NIINS	20
		595	828	564	2311	2243	619	53		UNITS	7,215
		42	166	427	3699	12359	9270	4125		EXT PRICE	32,088
20		1	2	2	7	3	6	1		NIINS	22
		433	2284	2340	2420	869	1003	50		UNITS	9,399
		43	277	1378	4448	5130	14599	11182		EXT PRICE	37,057
21			7	3	5	5	3	3		NIINS	26
			13097	885	10887	1966	433	207		UNITS	27,425
			4200	614	22717	10982	5726	12880		EXT PRICE	57,119

DEMAND VALUE STRATIFICATION

FILLP LOAD LIST VALUE STRATIFICATION TIMEFRAME 7608 THRU 7610 PHRS FCTR 1.000 PAGE 1

U/P VALUE RANGE	NIINS	UNITS	EXT PRICE
.00			
.01 TO .10	701	1217505	51,384
.11 TO .50	1475	2040620	555,957
.51 TO 1.00	1184	782065	542,264
1.01 TO 3.00	2086	767815	1,290,838
3.01 TO 10.00	2297	210695	1,013,059
10.01 TO 50.00	2533	91600	1,866,527
50.01 TO 500.00	1682	12840	1,824,063
500.01 AND OVER	347	2000	4,425,914
TOTALS	12,305	5,125,140	11,570,006

LOAD LIST VALUE STRATIFICATION

FILLP PROJECTED FREQ STRATIFICATION TIMEFRAME 7608 THRU 7610 RANGE CUT 1.000 PAGE 1

PROJECTED FREQ RANGE	LOAD MIINS	DEMAND MIINS	DEMAND FREQ	CUMULATIVE DMD FREQ	CUMULATIVE FREQ EFF
195.375	1	1	14	14	.03
173.375	1	1	23	37	.10
129.750	1	1	12	49	.13
113.975	1	1	8	57	.15
113.250	1	1	52	109	.29
100.750	1	1	55	164	.45
92.875	1	1	45	209	.57
91.500	1	1	52	261	.71
89.250	1	1	7	268	.73
87.500	1	1	49	317	.87
83.750	1	1	28	345	.94
80.750	1	1	30	375	1.03
79.500	1	1	45	420	1.15
77.750	1	1	55	475	1.30
76.875	1	1	41	516	1.41
76.000	1	1	43	559	1.53
75.375	1	1	30	589	1.61

PROJECTED FREQUENCY STRATIFICATION

Cog Stratification

In this report, the Load List items, demand items, total demand frequency, total demand quantity, and total demand value are printed for each Cog. Page 8-17 contains an example.

Project Code Stratification

This final optimal report lists for each Project Code and for each Cog within the Project Code the number of items demanded and the total demand frequency, quantity, and value. Project totals are also produced. An example is given on page 8-18.

FILLP COG STRATIFICATION TIMEFRAME 7608 THRU 7610 PWRS FCTR 1.000 PAGE 1

COG	LOAD NIINS	DEMAND NIINS	TOTAL DMD FREQ	TOTAL DMD QTY	TOTAL DMD VALUE
1H	1377	660	1881	11574	319989
1R	2				
2F	1				
2H	86	31	47	123	149985
2J	2	2	4	4	24550
2S	2				
2U	1	1	2	2	3780
2Z	4	3	10	11	32300
4G	104	51	140	210	205384
4N	195	61	128	209	149390
6G	10	8	12	16	30562
6O	1				
6U	19	10	28	32	13659
9A	9	6	15	58	1137
9C	1533	888	2797	33833	291902
9D	288	255	1935	74489	223074
9E	2	2	3	5	115
9G	1903	1291	6415	185122	413434

COG STRATIFICATION

FILL4 PROJECT CODE STRATIFICATION   TIMEFRAME 7608 THRU 7610   PWRS FCTR 1.000   PAGE 6

PROJECT CODE	COG	DEMAND NIINS	DEMAND FREQS	DEMAND QTYS	DEMAND VALUE
405	9D	7	7	11	144
405	9G	1	2	11	25
405	9N	1	1	1	2
405	9Q	3	3	33	48
PROJECT TOTALS		12	13	56	219
4PJ	9D	2	2	21	112
PROJECT TOTALS		2	2	21	112
4P2	9G	1	1	21	3213
PROJECT TOTALS		1	1	21	3,213
4P5	1H	2	2	6	309
4P5	9A	1	1	20	2
4P5	9C	14	18	178	539
4P5	9D	55	109	409	8337
4P5	9G	46	62	4467	4143
4P5	9L	2	2	15	78
4P5	9N	56	75	1041	519
4P5	9Q	73	90	1318	4441
4P5	9Y	5	6	52	125
4P5	9Z	33	45	1221	381
PROJECT TOTALS		207	410	8,927	18,874

PROJECT CODE STRATIFICATION

IX

READY REFERENCE GUIDE

This Ready Reference Guide consists of an expanded treatment of the formats and contents of the communications between the UICP Load List procedures and the user. The guide has been divided into three principal areas: the demand, the FIRL/FILL procedures, and the TARSLL procedures.

PREPARATION OF DEMAND INPUT

The preparation of both FIRL/FILL and TARSLL Load Lists requires accurate and timely demand data. For this reason, all MLSF demand reporting activities are required to forward to FMSO at the end of each month, demand documents for that month's transactions as well as any documents required to cancel previously reported transactions.

Demand documents from mechanized Load List demand reporting activities are to reach FMSO by the 15th day after the close of the business day for the reporting month. Demand documents from non-mechanized activities are to reach FMSO by the 10th day after the close of the business day for the reporting month.

Demand transactions may be submitted on magnetic tape, punched card, or offset type demand documents. Transactions submitted on the first two media require no preliminary action. However, transactions submitted on offset type documents must be key punched into the approved demand transaction format.

Demand is assigned to two categories: Category 1 demand is made up of industrial demand transactions--the demand must be the result of work performed for supported fleet units. Category 2 demand is Fleet Issue demand--the resupply requisitions for material placed by customer ships on the MLSF units.

Approved Demand Transaction Format

The standard punched card format (magnetic tape format is identical) is:

Card Column	Description
1	Record Type (always 1)
2	Demand Category (1 or 2)
3-5	Project Code
6-7	Blank
8-20	National Stock Number, Navy Item Control Number, or "I" Cog Ordering Number
21-22	Blank
23-24	Unit of Issue
25-29	Demand Quantity
30-43	Document Number
30-35	Requesting Ships UIC
36-39	Julian Data
40-43	Serial Number
44-54	Blank

Card Column	Description
55-56	Cognizance Symbol
57	Blank
58-62	Demand Reporting Activity UIC
63-65	Blank
66-69	Reporting Date (year and month)
70	Transaction Code: R - issue G - not in stock B - not carried
71-75	Serviced Ship UIC (required for category 1 demand)
76-80	Blank

Error/Review List

Demand transactions that are rejected during the validation process are printed in NIIN sequence on an Error/Review List. The format used on the listing is almost identical to the original transaction format. An example is shown on page 9-4. All items shown have quantity errors. Units of issue preceded by an asterisk are in error.

There are two primary reasons why a demand transaction may appear on an error/review listing. The first results from a demand quantity that is zero, non-numeric, or excessive. The second reason is an improper unit of issue.

RECORD TYPE — DEMAND CAT — PROJECT CODE — NSN — UNIT OF ISSUE — QUANTITY — REQUEST SHIP UIC — JULIAN DATE — SERIAL NO. — COG — REPORTER UIC — REPORTING DATE — TRANSACTION CODE — SERVICED SHIP

```
12ZX951200030523061   EA00001I 62649              F9Q 62649   7705R          62649
12ZX951200001897921   JE000=1  62649              F9Q 62649   7705R          62649
12ZX948200022701621   EA00000  62649              F9C 62649   7705R          62649
12ZX980100002869081   DC00(11  62649              F9Q 62649   7705R          62649
12ZX951100023465281   WE000=4  62649              F9Q 62649   7705R          62649
11GK540200065611251   SLR0000  0881071094104       9Z 08810   7705B03885     03885
12YY934390020438551   EA0000J  5702071041118       9G 00314   7705R          57020
12YY959350072104951   00019N   3467171323063       9N 00314   7705R          34671
12LE553300062740851   EA00000  0313371254531      F9Z 00651   7705R          03133
12FK058450037072161   EAL3331  050766286W0X9     1 1H 04689 F 7705B04689     05076
```

EXAMPLE OF ERROR/REVIEW LIST

Correcting Demand Transactions

Corrections of demand quantity or unit of issue are submitted to the Load List operation on E22AE1C cards.

Selected demand history entries in the MLSF Demand History File may be changed, if necessary, by using an E22FA1C card.

FIRL/FILL LOAD LISTS

The Fleet Issue Requirements List (FIRL) is an element of the Navy's Prepositioned War Reserve Requirement (PWRR). A FIRL includes most categories of secondary items required to support approved fleet forces. Excluded item categories include ammunition, bulk petroleum, subsistence, and ship's store stock.

There are two FIRLs produced each year; one for the Atlantic Fleet (LANTFIRL) and one for the Pacific Fleet (PACFIRL).

The UICP Load List procedures compute the range and depth of material required to provide a specified level of resupply support for a specified period of time.

The Fleet Issue Load List (FILL) is that portion of the FIRL that is positioned on a given Combat Store Ship (AFS) or selected ashore activities.

The FIRL/FILL is published by FMSO as Chapter IV of the Consolidated Loat Requisitioning Guide, Overseas (CARGO).

The FIRL/FILL development follows a Program Management Plan (PMP) that prepared and distributed by FMSO's Load List Branch (Code 9111). An ex- ɔle of the milestones that appear on the plan were presented in Chapter V.

The major elements of the plan where there is human interaction with the ɔP procedures are described in the following sections.

? Preparation of Technical Overrides

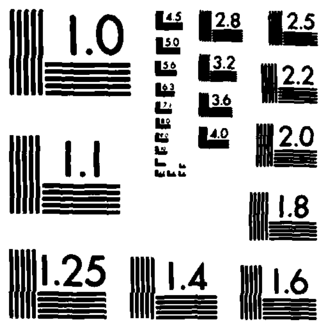
FMSO's Load List Branch has the responsibility of preparing the "Top 40" sting; those systems and equipments that have had three or more CASREPTs ɜr the past year. (An example page from a CASREPT listing is shown on the ɛt page.) This listing is reviewed by the Load List Branch to remove obvious ı-Load List items and is forwarded to SPCC's Allowance Division where the ɹs related to the Top 40 equipments are identified.

These APL numbers are forwarded to FMSO where they are used to extract ɪse NIINs that experience three or more CASREPTs (from the CASREPT data e) or a usage of three or more (from the 3-M data base) over the year.

Those NIINs are then reviewed by SPCC's Allowance Branch and Stock trol. Stock Control obtains a Consolidated Stock Status Report (CSSR) each NIIN and annotates the CSSR with their recommendation. A recom- dation may or may not be accepted by the Allowance Branch depending on cumstances.

AD-A099 777 SURVEY AND ASSESSMENT OF MODELS OR DECISION RULES DETERMINING SPARE PARTS..(U) AUTOMATION INDUSTRIES INC SILVER SPRING MD VITRO LABS DIV R I POWELL ET AL. 3/10

UNCLASSIFIED 07 SEP 79 TR-03133.100-1-APP-A F/G 15/5 NL



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

B-HITS APL SEQUENCE LIST FOR REPORT PERIOD ENDING JUN-76
ELECTRONIC

COG	NSN/FSN/PART NUMBER	SMIC	APL/CID NUMBER	FSN NOMENCLATURE	SHIP TYPE	HULL NR	EIC NUMBER	JOB CONTR NR	REFERENCE SYMBOL NR	R C	R A	ALL CD	O/B CD	UI	RQN QTY	REQ QTY
2Z	5820-00-134-0276		52389025	TRANSMITTER,RADIO	AOR	0004	QE07000	DE011099		2	S	NO	NO	EA	1	1
2Z	5820-00-134-0276		52389025	TRANSMITTER,RADIO	CG	0011	QE1N000	N0020734		2	S	NO	NO	EA	1	1
2Z	5820-00-134-0276		52389025	TRANSMITTER,RADIO	DD	0881	QE1N000	00000043		2	S	NO	NO	EA	1	1
2Z	5820-00-134-0276		52389025	TRANSMITTER,RADIO	LPH	0012	QE1N000	DE020957		2	S	NO	NO	EA	1	1
1H	1285-00-138-2566		52389025	CASE ASSEMBLY	CG	0016	QE1N000	DE02C244		2	R	NO	NO	EA	1	1
1H	1285-00-138-2566		52389025	CASE ASSEMBLY	LPD	0009	QE1N000	DE011693		2	S	NO	NO	EA	1	1
1H	1285-00-138-2566		52389025	CASE ASSEMBLY	LSD	0039	QE1N000	0000M007		2	R	NO	NO	EA	1	1
9N	5905-00-153-4576		52389025	RESISTOR,FIXED,FILM	AE	0033	QE1N000	DE010910		2	T	001	NO	EA	2	2
9N	5905-00-153-4576		52389025	RESISTOR,FIXED,FILM	DDG	0006	QE1N000	CF01M089	A1A1R1	2	S	NO	NO	EA	2	2
9N	5905-00-153-4576		52389025	RESISTOR,FIXED,FILM	DDG	0015	QE1N000	CF021204	1A1R25	2	S	NO	NO	EA	2	2
9N	5905-00-153-4576		52389025	RESISTOR,FIXED,FILM	LSD	0035	QE1N000	CE012156	1A1R25	2	S	NO	NO	EA	4	4
9N	5905-00-153-4576		52389025	RESISTOR,FIXED,FILM	SSN	0667	QE1N000	DC010261	1A1A1R1-2	2	T	001	001	EA	1	2
4G	5820-00-167-7673		52389025	TRANSLATOR SYNTHESI	AOR	0004	QE07000	DE011017	1A2A6	2	S	YES	001	EA		1
4G	5820-00-167-7673		52389025	TRANSLATOR SYNTHESI	AOR	0003	QE1N000	DE01M019	2A2A6	2	S	YES	NO	EA	1	1
4G	5820-00-167-7673		52389025	TRANSLATOR SYNTHESI	AOR	0005	QE1N000	DE01M021		2	T	004	NO	EA	2	1
4G	5820-00-167-7673		52389025	TRANSLATOR SYNTHESI	AOR	0005	QE1N000	DE01M019		2	S	004	NO	EA	2	1
4G	5820-00-167-7673		52389025	TRANSLATOR SYNTHESI	ARS	0041	QE1N000	CE01038R		2	S	001	NO	EA	1	1
4G	5820-00-167-7673		52389025	TRANSLATOR SYNTHESI	DDG	0006	QE1N000	GE01M089	1A2A6	2	S	001	NO	EA	1	1
9N	5960-00-230-8366		52389025	ELECTRON TUBE	AFS	0007	QE1N000	DE010960		2	T	002	NO	EA	6	6
9N	5960-00-230-8366		52389025	ELECTRON TUBE	DD	0819	QE07000	DE01C399	1A1A1V1	2	S	002	NO	EA	2	2
9N	5960-00-230-8366		52389025	ELECTRON TUBE	DD	0849	QE1N000	DE21C289	V1/V2	2	T	002	NO	EA	2	2
9N	5960-00-230-8366		52389025	ELECTRON TUBE	LCC	0020	QE1N000	CF030497	1A1V1/V2	3	S	NO	006	EA	2	2
9N	5960-00-230-8366		52389025	ELECTRON TUBE	SSN	0603	QE1N000	DC010335		2	T	001	001	EA	1	2
1H	5935-00-243-6696		52389025	SHIELD,ELECTRICAL C	CV	0041	QE07000	DE021060	1A2P3	2	S	NO	NO	EA	1	1
1H	5935-00-243-6696		52389025	SHIELD,ELECTRICAL C	DD	0881	QE1N000	00000043	1A2P3	2	S	NO	NO	EA	1	1
1H	5935-00-243-6696		52389025	SHIELD,ELECTRICAL C	DDG	0003	QE1N000	GF01E954	1A2P3	2	T	NO	NO	EA	1	1
1H	5935-00-243-6696		52389025	SHIELD,ELECTRICAL C	DDG	0003	QE1N000	CE01E934		2	T	NO	NO	EA	1	1
1H	5935-00-243-6696		52389025	SHIELD,ELECTRICAL C	LSD	0039	QE1N000	0000M007		2	R	NO	NO	EA	1	1
1H	5935-00-243-6696		52389025	SHIELD,ELECTRICAL C	LST	1186	QE1N000	DE01079A	1A2P3	3	S	NO	NO	EA	1	1
1H	5935-00-243-6696		52389025	SHIELD,ELECTRICAL C	LST	1187	QE1N000	GE01A140	P-3	2	T	NO	NC	EA	1	1
9N	5945-00-244-8430		52389025	RELAY,ARMATURE	AOR	0004	QE07000	DE011012	1A1K5	2	S	NO	NO	EA	1	1
9N	5945-00-244-8430		52389025	RELAY,ARMATURE	CV	0041	QE1N000	DE021042	1A1K5	2	S	NO	NO	EA	1	1
9N	5945-00-244-8430		52389025	RELAY,ARMATURE	DDG	0006	QE1N000	DE01M069	1A1K5	2	S	NO	NO	EA	1	1
9N	5945-00-244-8430		52389025	RELAY,ARMATURE	LCC	0020	QE1N000	CE030501	1A1K5	3	S	NO	001	EA	1	1
9N	5945-00-244-8430		52389025	RELAY,ARMATURE	LCC	0020	QE1N000	GF030497	1A1R5	3	S	NO	NO	EA	1	1
9N	5945-00-244-8430		52389025	RELAY,ARMATURE	LPH	0011	QE1N000	CE011681	1A1K5	2	S	NO	NO	EA	1	1
9N	5945-00-244-8430		52389025	RELAY,ARMATURE	LPH	0011	QE1N000	GE011725	1A1K5	2	S	NO	NO	EA	1	1
9N	5905-00-249-3642		52389025	RESISTOR,FIXED,COMP	AOR	0004	QE07000	DE011012	1A1A7R-3	2	S	YES	003	EA		3
9N	5905-00-249-3642		52389025	RESISTOR,FIXED,COMP	ARS	0041	QE1N000	DE010309		3	S	NO	NO	EA	3	3
9N	5905-00-249-3642		52389025	RESISTOR,FIXED,COMP	DD	0849	QE1N000	DE21C289	1A1A7R3	2	T	001	NO	EA	2	2
9N	5905-00-249-3642		52389025	RESISTOR,FIXED,COMP	FF	1089	QE1N000	DE01M123	1A1A7R1,2,3	3	S	YES	NO	EA	3	3

Those items that pass a final review by the Allowance Branch will make up the preliminary FILL and card deck. Quantities, generally one per FILL, will be punched on the cards.

New equipments may also be nominated for inclusion on the FILL. The nominations are initiated by the Fleet CINC and reach SPCC by way of CNO/NAVSUP. The nominations must be matched to the applicable APL using either a hard copy of the APLs or the Weapon System File.

These APLs will be reviewed and all that are repairable at the organizational level will be extracted.

The extracted NIINs will be reviewed by both the Allowance Division and Stock Control in a manner similar to that used in the Top 40 review.

The NIINs remaining after the review are combined with those from the Top 40 review and the override candidates are forwarded to FMSO.

Frequency Distributions

Frequency distributions for both equipment-related and non-equipment-related items are prepared as part of the FIRL/FILL process. An example of the ER frequency distribution is shown on the next page. The axes of the frequency distribution are deployed (FILL) demand frequency and expanded (FIRL) demand frequency. Each cell shows the number of items experiencing at least the demand frequencies shown on the axes. For example, the circled number indicates that 4,899 items had a deployed demand frequency of 4 or more and an expanded demand frequency of 9 or more.

If we know the maximum number of items that the TYCOM wants to include on the list, we can determine which range cut values will produce a range that is close to the desired number. These range cuts, after approval, can then be introduced into the operation as a means of limiting the Load List range.

FILL Statistics Supplied to NAVSUP

At the conclusion of the FIRL/FILL process, statistics are provided to NAVSUP for approval. These statistics are concerned with the number of items added to the list and their extended value, the number of items whose quantity was increased and their extended value, the number of items whose quantity was decreased and their extended value, and the number of items detected from the Load List and their extended value.

The statistics are broken down by Budget Project which is made up of designated Cogs.

Budget Project	Cogs
14	1A, 1H
15	1I
18	9D
19	1N
23	1W
25	1B
28	9A, 9B, 9C, 9E, 9F, 9G, 9H, 9I, 9J, 9L, 9N, 9Q, 9S, 9V, 9W, 9Y, 9Z
34	1R
35	5R
38	9X

E R F I L L C A N D I D A T E S

NUMBER OF ER FILL ITEMS WITH HAND/MIN OVERRIDE — 1.250 — TOTAL FILL (EXPANDED) FREQUENCY

TOTAL FILL (DEPLOYED) FREQUENCY

	0	1	2	3	4	5	6	7	8	9	10
0.	12500	12500	12500	12500	12500	12500	12500	12500	12500	11100	9954
1.	9796	9796	9796	9796	9796	9796	9796	9796	9796	9033	8395
2.	7705	7705	7705	7705	7705	7705	7705	7705	7705	7333	6968
3.	6125	6125	6125	6125	6125	6125	6125	6125	6125	5957	5775
4.	4982	4982	4982	4982	4982	4982	4982	4982	4982	4099	4807
5.	4136	4136	4136	4136	4136	4136	4136	4136	4136	4091	4036
6.	3493	3493	3493	3493	3493	3493	3493	3493	3493	3472	3444
7.	3017	3017	3017	3017	3017	3017	3017	3017	3017	3006	2990
8.	2627	2627	2627	2627	2627	2627	2627	2627	2627	2622	2613
9.	2310	2310	2310	2310	2310	2310	2310	2310	2310	2309	2302
10.	2048	2048	2048	2048	2048	2048	2048	2048	2048	2047	2044
11.	1811	1811	1811	1811	1811	1811	1811	1811	1811	1811	1808
12.	1590	1590	1590	1590	1590	1590	1590	1590	1590	1590	1587
13.	1423	1423	1423	1423	1423	1423	1423	1423	1423	1423	1421
14.	1283	1283	1283	1283	1283	1283	1283	1283	1283	1283	1282
15.	1154	1154	1154	1154	1154	1154	1154	1154	1154	1154	1153
16.	1046	1046	1046	1046	1046	1046	1046	1046	1046	1046	1045
17.	958	958	958	958	958	958	958	958	958	958	958
18.	880	880	880	880	880	980	880	800	800	880	890
19.	803	803	803	803	803	803	803	803	803	803	803
20.	733	733	733	733	733	733	733	733	733	733	733
21.	666	666	666	666	666	666	666	666	666	666	666
22.	609	609	609	609	609	609	609	609	609	609	609
23.	562	562	562	562	562	562	562	562	562	562	562
>= 24.	531	531	531	531	531	531	531	531	531	531	531

The items and extended values are also related to Appropriation Purchases Account and Navy Stock Account. An example of a Naval Message showing these statistics is shown on the next several pages.

Quarterly FIRL/FILL Supplements

Supplements to each of the two FIRLs are prepared quarterly based on CASREPT and 3-M data over the previous three months. The necessary data for the supplement are extracted by FMSO and reviewed by FMSO's Load List Branch and SPCC's Allowance Division. Stock Control also reviews and makes recommendations which will, in turn, be accepted or rejected by the Allowance Division.

A punched card deck of verified adds with written recommendations will be forwarded to FMSO by SPCC for SPCC Cog items. FMSO's Load List Branch then prepares the supplement.

TENDER AND REPAIR SHIP LOAD LISTS

TARSLLs are produced by FMSO to enable the tenders and repair ships to meet their industrial missions—the repair of equipments on board the ships for which the tenders are responsible. TARSLLs are also designed to enable submarine tenders to meet their resupply mission.

There are two distinct range and depth procedures in the TARSLL—one for conventional tenders and the other for FBM tenders.

NAVAL MESSAGE
OPNAV FORM 2110/26 (REV. 3-69) S/N-0107-LF-708-4001

RELEASED BY	DRAFTED BY	PHONE EXT NR	PAGE	PAGES
P Clarke	K. BENNETT	2337	1 of	3

DATE	TOR/TOD	ROUTED BY	CHECKED BY
8 JUN 1977			

MESSAGE NR	DATE/TIME GROUP	PRECEDENCE	FLASH	IMMEDIATE	PRIORITY	ROUTINE
	110533	ACTION				X
		INFO				X

FROM: FLEMATSUPPO MECHANICSBURG PA

TO: COMNAVSUPSYSCOM WASHINGTON DC

INFO: COMNAVSURFLANT NORFOLK VA

UNCLAS //N04441//

1977 ATLANTIC FILL STATISTICS

A. FMSO LTR 9111K 4441 FIRL/FILL SER 383 OF 8 DEC 76

1. THE FOLLOWING STATISTICS ARE PROVIDED IN ACCORDANCE WITH MILESTONE 23 OF REF A:

	TOTAL ADDS	BUDGET PROJECT	TOTAL VALUE
	716	14	$ 139,164
	12	15	350
	44	18	22,426
	2,561	28	122,476
	3	34	1,209
NSA	3,336		$ 285,625
APA	251		504,189
TOTAL	3,587		$ 789,814

UNCLASSIFIED

DATE/TIME GROUP

MESSAGE
NAV FORM 2110/28 (REV. 3-69) S/N-0107-LF-704-1001

RELEASED BY	DRAFTED BY	PHONE EXT NR	PAGE	PAGES
	K. BENNETT	2337	2 of	3

DATE	TOR/TOD	ROUTED BY	CHECKED BY
8 JUN 1977			

MESSAGE NR	DATE/TIME GROUP	PRECEDENCE	FLASH	IMMEDIATE	PRIORITY	ROUTINE
		ACTION				X
		INFO				X

	TOTAL INCREASES	BUDGET PROJECT	TOTAL VALUE
	32	14	$ 5,386
	27	15	3,645
	77	18	37,372
	783	28	105,054
NSA	919		$ 151,457
APA	-		-
TOTAL	919		$ 151,458

	TOTAL DECREASES	BUDGET PROJECT	TOTAL VALUE
	91	14	$ 21,043
	144	15	20,090
	67	18	38,338
	1,827	28	204,197
NSA	2,129		$ 283,668
APA	-		-
TOTAL	2,129		$ 283,668

110533

UNCLASSIFIED

DATE/TIME GROUP

MESSAGE

NAV FORM 2110/28 (REV. 3-69) S/N-0107-LF-708-4001

RELEASED BY	DRAFTED BY	PHONE EXT NR	PAGE	PAGES
	K. BENNETT	2337	3 of	3

DATE	TOR/TOD	ROUTED BY	CHECKED BY
8 JUN 1977			

MESSAGE NR	DATE / TIME GROUP	PRECEDENCE	FLASH	IMMEDIATE	PRIORITY	ROUTINE
		ACTION				X
		INFO				X

	TOTAL DELETES	BUDGET PROJECT	TOTAL VALUE
	296	14	$ 69,539
	219	15	19,741
	66	18	9,661
	1,608	28	84,985
	1	34	106
NSA	2,190		$ 184,032
APA	111		230,896
TOTAL	2,301		$ 414,928

FULL RANGE

NSA	13,473		$ 1,590,689
APA	571		1,072,825
TOTAL	14,044	VALUE	$ 2,663,514

2. REQUEST AUTHORITY TO RELEASE SUPPLY AIDS.

110533

UNCLASSIFIED

DATE/ TIME GROUP

The TARSLL development follows a Program Management Plan (PMP) similar to that used in the FIRL/FILL process. The TARSLL PMP is prepared and distributed by FMSO's Load List Branch. An example of the PMP was given in Chapter VI.

The major elements of the plan where there is human interaction with UICP operation are described in the sections that follow.

Obtaining the Candidate Listing and Preparing Pre-Model Overrides

SPCC's Allowance Division is supplied the required hull mix for the TARSLL by the TYCOM via letter or message. SPCC validates the hull mix UICs. (Special procedures are followed if nuclear UICs are to be included.) The required item data is then extracted from the Weapon System File, Master Data File, and the Program Support Interest File.

The preliminary candidate listing resulting from the extract as well as any error listings produced are reviewed by SPCC.

Overrides to the candidate listing are prepared on punch cards and forwarded to FMSO with the listing and candidate tape. FMSO also reviews the listing and prepares overrides as appropriate.

Review and SKIM Listings for Post-Model Changes

In this section we shall discuss the formats of the various review and SKIM listings. These post-model outputs are reviewed by SPCC (Allowance Division) and FMSO (Load List Branch).

Edited Candidate Review Record (E17MA1L)

An example of this review listing is shown on page 9-17. The format is:

Column	Description
1	NIIN or NICN
2	Special Material Identification Code
3	Federal Supply Class
4	Cognizance Symbol
5	Item Name
6	Unit Price
7	Unit of Issue
8	New Load List Quantity
9	Old Load List Quantity
10	Override Code
11	Override Quantity
12	Ship Installable Population
13	Tender Installable Population
14	Demand Frequency
15	Demand Quantity
16	Best Replacement Factor
17	Minimum Replacement Unit Quantity
18	Review Code
	1st pos. D - Item deleted from Load List
	A - Item added to Load List
	I - Load List quantity has increased
	M - Load List quantity has decreased
	blank - New and old quantities are the same

AS 11 | REVIEW LIST | 05-09-77 | PAGE 118

NIIN	SM IC	FSC	CDG	NAME	UNIT PRICE	UN /I	NEW QTY	OLD QTY	OR	AVAGE QTY	SHIP PDP	TENDER PDP	DMD FREQ	DMD QTY	BEST REP EPC	MHV	REV CODES 1 2 3 4 5	HIC
007708388		2040	1H	WEDGE	00001.50	EA	20	4		0	0	0	5	165	00.0000	1	A 0 D	
007708389		2040	1H	WEDGE	00001.50	EA	19	0		0	0	0	5	163	00.0000	1	A 0 D	
00771?428		4720	1H	HOSE	00001.60	FT	90	90		0	840	0	8	86	02.0600	1	P 0 D	97999 0001
007722?00	CC	5910	1H	CIRCU	00024.00	EA	1	0		0	260	0	4	0	00.0091	1	A 0	92601290 92601290PA
007730253		5845	1H	AMPLI	00037.00	EA	0	1		0	36	0	3	0	00.0498	1	D	52240501
007732782		5950	1H	COIL	00022.50	EA	8	1		0	554	0	14	24	00.0155	1	I P 0 D	NONE
007732786		5950	1H	COIL	00040.00	EA	7	1		0	436	0	2	25	00.0125	1	I P U C	NONE
007732042		1355	1H	RETAI	00009.30	EA	7	4		0	0	120	20	0	00.0850	1	A 0 D	0043c0009
007747600		4140	1H	FAN C	00175.00	EA	0	1		0	5	0	2	9	00.0653	1	D	28300009 28200009
007751359		1450	1H	PIN V	00000.23	EA	5	4		0	0	0	2	0	00.0000	1	A 0 0	
007752561		4820	1H	VALVE	00031.50	EA	2	2		0	44	0	5	0	00.1150	2	0 D	NONE
007761627		5360	1H	SPRIN	00002.20	EA	7	7		0	7	0	11	0	00.7961	1	0 D	99001 0010
007761631		5360	1H	SPRIN	00001.20	EA	4	4		0	7	3	6	0	00.4395	1	0	99C01 0010
007761640		5360	1H	SPRIN	00001.01	EA	5	5		0	7	0	6	0	00.4799	1	0	99001 0010
007761655		5310	1H	WASHE	00208.00	EA	1	7		0	7	0	10	0	00.7642	1	M P 0 G	99001 0010
007761658		5310	1H	WASHE	00000.24	EA	12	12		0	7	0	15	0	01.1386	1	0 D	99001 0010

EDITED CANDIDATE REVIEW RECORD
(E17MAIL)

Column		Description
	2nd pos:	V - data void
		blank - no data void
	3rd pos:	P - Extended price exceeds specified value
		blank - Extended price within bounds
	4th pos:	Q - Quantity exceeds specified value
		blank - Quantity within bounds
	5th pos:	D - Quarterly demand forecast exceeds specified value
		blank - Quarterly demand forecast within bounds
19		Application Code : up to 4 identifiers of higher level items to which NIIN of record is related.

Preliminary Load List (E17RC1L)

An example of this second review listing is shown on page 9-19. The format for this listing is:

Column	Description
1	Cognizance Symbol
2	NIIN or NICN
3	Special Material Identification Code
4	Item Name
5	Unit of Issue
6	Unit Price Code: E - Non-Standard Blank - Standard
7	Unit Price
8	Net Cube of Item

AS II LOAD LIST SLCT II 09-29-77

CDE	STOCK NUMBER		IC	ITEM NAME	U/I	UNIT PRICE	W/CUBE	LOAD QTY	MANAGEMENT DATA A	B	C	D	E	F	G
1H	1650	007537605		FILTER ELEMENT,FLUI	EA	112.10	.	1	1	U		0	00		M
9N	5965	002553701		RESISTOR,FIXED,COMP	EA	.12	.0010	9	1	U		0	00		
96	8250	002554215		LAMPHOLDER	EA	1.03	.0080	8	1	U		0	00		
96	3438	002554971		FLUX,SOLDERING	CN	.19	.0130	6	1	U		0	00		
96	3439	002554977		FLUX,WELDING	LB	.07	.0210	2	1	U	B	0	00	T	
9N	5603	002554987		RESISTOR,FIXED,FILM	EA	.04	.0000	29	1	U		0	00		
9Q	6140	002555719		BATTERY,STORAGE	EA	53.80	.	8	4	U		0	00		
9Q	6140	002555721		BATTERY,STORAGE	EA	41.09	.	1	1	U		0	00		
1H	9905	002555729		HOLDER,CARD-LABEL	EA	7.30	.	1	1	U		0	00		M
1H	9905	002555930		HOLDER,CARD-LABEL	EA	7.80	.	1	1	U		0	00		M
1H	9905	002555931		HOLDER,CARD-LABEL	EA	5.90	.	1	1	U		0	00		M
1H	9905	002555937		HOLDER,CARD-LABEL	EA	52.00	.	1	1	U		0	00		M
1H	9905	002555916		HOLDER,CARD-LABEL	EA	21.50	.	1	1	U		0	00		M
9C	7330	002555995		PAN,BREAD	SE	21.94	.	1	1	U		0	00		
9Z	5330	002556975		GASKET	EA	.67	.0010	6	2	U		0	00		
9Z	5330	002556991		GASKET	EA	.03	.0003	34	1	U		0	00		
9Q	7020	002557336		BRUSH,CHASSIS AND R	EA	1.97	.	1	1	U		0	00		
9Q	3439	002557711		ELECTRODE,CUTTING,T	LB	1.42	.	1	1	U		0	00		
9Q	4140	002557798		FAN,CIRCULATING	EA	62.06	.0750	1	1	U		0	00		
9Q	4140	002557801		FAN,CIRCULATING	EA	81.32	1.5000	1	1	U		0	00		
9D	8415	002558577		APRON,FOOD HANDLERS	EA	.85	.	2	1	U		0	00		
9N	5961	002559075		TRANSISTOR	EA	15.00	.0000	4	1	U		0	00		
9Q	4130	002559108		RING,PISTON	EA	.58	.0320	9	3	U		0	00		
9Q	4130	002559112		RING,PISTON	EA	.51	.0500	6	6	U		0	00		
9Q	4130	002559114		RING,PISTON	EA	2.19	.0100	4	2	U		0	00		
9Q	6685	002559516		TEMPERATURE INDICAT	EA	2.65	.	1	1	U		0	00		
9N	5960	002560001		ELECTRON TUBE	EA	7.75	.0030	3	1	U		0	00		
9Z	5330	002560169		PACKING,PREFORMED	EA	.15	.0010	56	8	U		S	00		
9Z	5330	002560180		PACKING,PREFORMED	EA	.10	.1000	48	3	U		S	00		
9Z	5330	002560185		PACKING,PREFORMED	EA	.09	.0210	42	1	U		S	00		

PRELIMINARY LOAD LIST
(E17RC1L)

Column	Description
9	Military Essentiality Code (FBM only)
10	Repairable Identification Code (FBM only)
11	Load List Quantity
12	Management Data

Quantity SKIM

This SKIM output lists the Load List items in order of increasing quantity. An example of this SKIM is shown on page 9-21. The format is:

Column	Description
1	NIIN
2	Special Material Identification Code
3	Federal Supply Class
4	Cognizance Symbol
5	Item Name
6	Control (Load List Quantity)
7	Unit Price
8	Unit of Issue
9	New Load List Quantity
10	Old Load List Quantity
11	Override Code
12	Override Quantity
13	Ship Installable Population
14	Tender Installable Population

NIIN	SMIC	FSC	COG	NAME	CONTROL	PRICE	U/I	MFD	OLD	OR QTY	S-POP	T-POP	FHCQ	DMD QTY	RIC
004032838		6505	9L	SODIUM CHL	00000051	00000008/	PG	00051	00000	00000	000000	000000	00003	000080	
009135974		5310	9Z	NUT,PLAIN,	00000051	00000013	EA	00051	00000	00000	000034	000000	00007	000086	0A0070001
009244903		6505	9L	ATROPINE I	00000051	00000102	EA	00051	01400	00000	000000	000000	00002	000200	
000439014		5330	9Z	PACKING,PR	00000052	00000074	EA	00052	00004	00000	000729	000008	00008	000089	241430001
001522911		5940	9G	TERMINAL,L	00000052	00000029	EA	00052	00023	00000	000000	000000	00002	000100	
002730428		2815	9C	RING,PISTO	00000052	00000019	EA	00052	00000	00000	000096	000000	00006	000090	645710046
004849309	83	5340	1M	ANODE,CORR	00000052	00000520	EA	00052	00000	00000	000008	000000	00009	000119	036040006
006409161		5330	9Z	PACKING,PR	00000052	00000007	EA	00052	00000	00000	000000	000008	00010	000129	
004431191		5330	9Z	RETAINER,P	00000052	00000013	EA	00052	00027	00000	000311	000000	00009	000084	NORF
007526727		5330	9Z	PACKING,PR	00000052	00000009	EA	00052	00000	00000	000108	000000	00016	000138	006340001
008176296		5360	9Z	SPRING,HEL	00000052	00000006	EA	00052	00016	00000	000392	000000	00001	000080	NORF
008391446		5330	9Z	RETAINER,P	00000052	00000004	EA	00052	00C12	00000	000430	000008	00094	000000	NORF
003743718		4465	1M	FILTER,ULT	00000052	00000200	EA	00052	00112	00000	000070	000008	00011	000178	394860009
009776209		5999	9N	CONTACT,EL	00000052	00000016	EA	00052	00026	00000	002582	000008	00002	000058	NORF
009665601		8480	9L	PAPER,FILT	00000052	000C1296	RC	00052	00004	00C00	000029	000000	00034	000172	69008100
006130372		3455	9U	SLEEVE, CE	00000053	00000173	EA	00053	00005	00000	000512	000000	00007	000064	169140002
000976402		5310	9Z	WASHER,FLA	00000053	00000209	EA	00053	00003	00000	000512	000000	00002	000064	169140002
002022559		5330	9Z	PACKING AS	00000053	00000030	AY	00053	00060	00000	000000	000000	00004	000118	

QUANTITY SKIM

Column	Description
15	Demand Frequency
16	Demand Quantity
17	Repairable Identification Code

Demand Frequency SKIM

This SKIM output lists the Load List items in order of increasing demand frequency. An example is shown in page 9-23. The format is the same as that used with the quantity SKIM except that Column 6, Control, now contains the demand frequency.

Price SKIM

This SKIM output lists the Load List items in order of increasing extended price (unit price times New Load List quantity). An example is shown on page 9-24. The format is the same as that used with the Quantity SKIM except that Column 6, Control, now contains the extended price.

NSN Sequence SKIM

This SKIM output lists the Load List items in NSN sequence. An example is given on page 9-25. The format is the same as that used with the Quantity SKIM except that Column 6, Control, is now blank.

77131 DEMAND FREQUENCY PAGE 711

NIIN	SMIC	FSC	COG	NAME	CONTROL	PRICE	U/I	NEW	OLD	DR QTY	S-POP	T-POP	FREQ	DMD QTY	RIC
004013226		5303	9Z	SHIM	000000001	000000016	EA	00026	00000	00000	001350	000000	00061	000000	005110196
004383525		5905	9H	RESISTOR,V	000000062	00000520	EA	00010	00001	00000	000026	000000	00062	000000	395110004
004870213		5961	9Y	SEMICONDUC	000000062	00000211	EA	00001	00000	00000	000012	000000	00062	000000	202850011
006977237		5945	9H	RELAY,ARMA	000000002	00001073	EA	00003	00000	00000	000024	000000	00062	000000	395110004
009172061		1220	1H	HOUSING,SH	000000062	00000060	EA	00007	00000	00000	000005	000000	00062	000000	005120001
009390832		5310	9Z	NUT,SELF-L	000000062	00000007	EA	00033	00000	00000	000135	000000	00062	000000	005110194
LLHONF14A	CPM2	1655	2M	PRONE,LIOU	000000061	00017500	EA	00001	00000	00000	000128	000000	00063	002000	169140002
LLH413562		2 4039	1H	PACKING,PER	000000063	00000500	EA	00010	00000	00000	000032	000000	00063	000000	005110076
000071231		5910	9Y	CAPACITOR,	000000063	00000009	EA	00033	00011	00000	002550	000101	00063	000000	400E
002831132	X3	4820	1H	DIAPHRAGM,	000000063	00001450	EA	00004	00000	00000	000066	000000	00063	000000	387020064
203121191		4730	9C	TEE,PIPE	000000063	00000214	EA	00031	00022	00000	000000	004536	00063	000000	090660002
004254703		5340	9Z	LOCKING PL	000000063	00000070	EA	00000	00000	00000	000032	000000	00063	000000	140020010
004383734		5905	9H	RESISTOR,V	000000063	00001800	EA	00000	00012	06000	000026	000000	00063	000000	395110004
0-063.772		7920	9Q	TOWEL,PAPE	000000063	00077209	[illegible]	00001	00001	00000	000000	000000	00063	000410	
009791087		5305	9Z	SCREW,CAPS	000000063	00000221	EA	00027	00001	00000	000066	000000	00063	000000	990010021
010133563		5310	9Z	RETAINER,P	000000063	00000420	EA	00012	00000	00000	000032	000000	00063	000000	520170460
010134020		5330	9Z		000000063	00000460	EA	00012	00000	00000	000032	000000	00063	000000	520170460

DEMAND FREQUENCY SKIM

77131						EXTENDED PRICE										PAGE 240
NIIN	SMIC	FSC	COG	NAME	CONTROL	PRICE	U/I	NEW	OLD	DD QTY	$-POP	I-POP	FREQ-DMD	QTY		MIC
008032920		2020	9Y	BRUSH,YARN	00000520	00000013	EA	00014	00020		00000	000000	000000	00020	000075	
000422571		5330	9Z	PACKING,PR	00000520	00000080	EA	00000	00006		00000	000044	000000	00003	000000	414370049
001074269		5350	9Y	CLOTH,ABRA	00000530	00000530	RO	00001	00000		00000	000000	000000	00002	000020	
002302397		5130	9Y	CHISEL,PUN	00000530	00000530	EA	00001	00000		00000	000000	000000	00003	000006	
002370574		5210	9Q	GAGE,HANDI	00000530	00000530	EA	00001	00000		00000	000000	000000	00003	000005	
002433787		5920	9Y	FUSE,CARTR	00000530	00000010	EA	00053	00053		00000	000469	000000	00004	000090	MORE
002827940		6685	9Q	THERMOMETE	00000530	00000530	EA	00001	00001		00000	000000	000000	00001	000005	
004750377	X3	9525	1M	WIRE,NONEL	00000530	00000530	RO	00001	00001	CS	00001	000075	000000	00002	000003	MORE
005522421		2905	1M	RESISTOR,A	00000530	00000530	EA	00001	00000		00000	000012	000000	00003	000009	020210006
008103019		4240	9Q	GOGGLES,IN	00000530	00000530	PR	00001	00000		00000	000000	000000	00003	000005	
008922355	1	2310	9Z	PACKING,PR	00000530	00000100	EA	00002	00000		00000	000010	000000	00007	000000	520290001
009016729		2330	9Z	GASKET	00000530	00000530	EA	00001	00001		00000	000000	000000	00004	000000	006335120
009264196	L1	4710	1M	TUBE,METAL	00000530	00000530	FT	00001	00000		00000	000000	000000	00003	000035	
001706920		2320	9Y	HICK	00000531	00000177	HD	00003	00000		00000	000201	000000	00004	000000	MORE
002633074		2020	9Y	BRUSH,PAIN	00000532	00000010	EA	00007	00025		00000	000000	000000	00012	000071	
162273375		3210	9C	NIPPLE,HGS	00000532	00000532	EA	00001	00001		00000	000000	000000	00009	000019	
005010058		4925	1M	CAP,SPLICE	00000532	00000420	EA	00019	00050		00000	000000	000000	00002	000060	
005762625		2360	9Z	SPRING,HEL	00000532	00000010	EA	00024	00000		00000	000000	612000	00052	000000	006300009

PRICE SKIM

77131

SKIP QUANTITY BY FSN

PAG 01

NIIN	SMIC	FSC	COG	NAME	CONTROL	PRICE	U/I	NEW	OLD	OR QTY	S-POP	T-POP	FREQ-DMD	QTY	RIC
009741732		4330	9C	FILTER ELE	00000000	00000090	EA	00003	00001	00000	000000	000000	00002	000011	
009830998		4330	9C	FILTER ELE	00003000	00000610	EA	00008	00000	00000	000004	000000	00001	000012	4R0120080
010031251		4330	9C	FILTER ELE	00000000	00000300	EA	00006	00000	00000	000007	000000	00013	000000	4R0050092
010121592		4330	9C		00000000	00051370	EA	00001	00000	00000	000009	000000	00005	000000	4R0060247
010190339	2	4330	1H	FILTER,ELE	00000000	00000250	EA	00008	00000	00000	000004	000000	00015	000000	4R0060593
005063601		4410	1H	HEATER COI	00000000	00003350	EA	00005	00005	00000	000130	000000	00004	000025	07C670007
000021143		4420	1H	PLUG,PENNA	00000000	00004700	EA	00001	00001	00000	000000	001552	00300	000000	040R00092
000021164		4420	1H	PLUG,PENNA	00000000	00001600	EA	00003	00000	00000	000000	007776	01604	000000	04026C001
000021167		4420	1H	PLUG,PENNA	00000000	00001350	EA	00009	00001	00000	000000	000672	00073	000000	04026C003
003030135		4420	1H	GASKET,COV	00000000	00000290	EA	00006	00000	00C00	000024	000000	00001	000008	03006C081
003036154		4420	1H	GASKET,ZIN	00000000	00000050	EA	00006	00000	00000	000016	000000	00001	000006	03008C087
006504670		4420	1H	JET PIPE A	00000000	00022100	EA	00001	00000	00000	000021	000000	00006	000000	61693C001
006504671		4420	1H	LANGE WRAP	00000000	00004400	EA	00001	00001	00000	000021	000000	00003	000004	61693C001
006504673		4420	1H	JEWEL WEAR	00000000	00002500	EA	00001	00000	00C00	000021	C00000	00005	000000	61693C001
009204252	43	4420	1H	LOCKING WE	00000000	00000140	EA	00009	00005	00000	C00048	000000	00001	000011	01699C001
001921007		4440	9C	CANTRIUGE,	00000000	00000652	EA	00018	00006	00060	000005	000000	00017	000047	325060002
001921030		4440	9C	CANTRIUGE,	00000000	00001695	EA	00001	00002	0C00C	CC0000	000000	00010	000037	
004752024		4440	9C	CANTRIUGE,	00000000	00002922	EA	00001	00001	00000	C00008	C00009	00005	000000	325060126

NSN SEQUENCE SKIM

TARSLL Statistics Supplied to NAVSUP

In the same fashion as FILL Statistics, TARSLL financial statistics are forwarded to NAVSUP for approval. An example of this is shown on the next several pages.

The format and Budget Projects used in this message are the same as for the FIRL/FILL statistics.

ROUTINE • U N C L A S S I F I E D •

PT 1233 179 220855

RTTUZYUW RULSSGG1361 1792201-UUUU--RUEDNAA.

ZNR UUUUU

R 281910Z JUN 77

FM COMNAVSUPSYSCOM WASHINGTON DC

TO RUEDNAA/FLEMATSUPPO MECHANICSBURG PA

INFO RHAPSPH/COMSUBPAC PEARL HARBOR HI

BT

UNCLAS //N04441//

1977 SUBASE PEARL HARBOR LOAD LIST

A. FMSO 161524Z JUN 77

B. FMSO LTR 91110/4441 SER 425 DTD 4 JAN 77

1. FINANCIAL STATISTICS FWDED REF A APPROVED.

2. FMSO AUTHORIZED TO RELEASE SUPPLY AIDS IAW M/S 13 OF REF B.

BT

#1361

NNNN

NAVAL MESSAGE
OPNAV FORM 2110/28 (REV. 3-69) S/N-0107-LF-703-4001

RELEASED BY	DRAFTED BY	PHONE EXT NR	PAGE	PAGES
[signature]	V. HICKEY	2337	1 of	3

DATE	TOR/TOD	ROUTED BY	CHECKED BY
15 JUNE 1977			

MESSAGE NR	DATE/TIME GROUP	PRECEDENCE	FLASH	IMMEDIATE	PRIORITY	ROUTINE
	161524	ACTION				X
		INFO				X

FROM: FLEMATSUPPO MECHANICSBURG PA

TO: NAVSUPSYSCOMHQ WASHINGTON DC

INFO: COMSUBPAC PEARL HARBOR HI

UNCLAS //N04441//

1973 SUBASE PEARL HARBOR LOAD LIST

A. FMSO LTR 9111C 4441 SER 425 OF 4 JAN 77

1. STATISTICS FOR SUBJ LOAD SUBMITTED IAW MILESTONE 11 OF REF (A).

	TOTAL ADDS	BUDGET PROJECT	TOTAL VALUE
	140	18	$ 4,263
	3	38	14
	6,364	28	252,204
	1,512	14	238,516
	17	34	3,505
NSA	8,036		$ 498,502
APA	319		490,759
TOTAL	8,355		989,261

UNCLASSIFIED

DATE/TIME GROUP

NAVAL MESSAGE
OPNAV FORM 2110/28 (REV. 3-69) S/N-0107-LF-705-4001

RELEASED BY	DRAFTED BY	PHONE EXT NR	PAGE	PAGES
	V. HICKEY	2337	2 OF	3

DATE	TOR/TOD	ROUTED BY	CHECKED BY
15 JUNE 1977			

MESSAGE NR	DATE / TIME GROUP	PRECEDENCE	FLASH	IMMEDIATE	PRIORITY	ROUTINE
		ACTION				X
		INFO				X

	TOTAL INCREASES	BUDGET PROJECT	TOTAL VALUE
	18	18	$ 1,606
	3,836	28	204,009
	573	14	66,636
NSA	4,427		$ 272,251
APA	2		3,069
TOTAL	4,429		$ 275,320

	TOTAL DECREASES	BUDGET PROJECT	TOTAL VALUE
	37	18	$ 12,161
	4,381	28	174,480
	774	14	139,079
	3	34	526
NSA	5,195		$ 326,246
APA	8		14,912
TOTAL	5,203		$ 341,156

UNCLASSIFIED

DATE/ TIME GROUP

NAVAL MESSAGE
OPNAV FORM 2110/28 (REV. 3-69) S/N-0107-LF-703-4001

RELEASED BY	DRAFTED BY	PHONE EXT NR	PAGE	PAGES
	V. HICKEY	2337	3 OF	3

DATE	TOR/TOD	ROUTED BY	CHECKED BY
15 JUNE 1977			

MESSAGE NR	DATE/TIME GROUP	PRECEDENCE	FLASH	IMMEDIATE	PRIORITY	ROUTINE
		ACTION				X
		INFO				X

TOTAL DELETES		BUDGET PROJECT	TOTAL VALUE
	142	18	$ 4,422
	8,533	28	332,210
	1	38	23,262
	2,212	14	362,771
	17	34	1,589
NSA	10,905		$ 724,254
APA	484		831,408
TOTAL	11,389		$1,555,662

2. FULL RANGE STATISTICS

	TOTAL ITEM COUNT	TOTAL VALUE
NSA	22,262	$ 1,501,028
APA	646	890,152
TOTAL	22,908	$ 2,391,180

3. REQUEST AUTHORITY TO RELEASE SUPPLY AIDS PER REF (A).

UNCLASSIFIED

DATE/TIME GROUP

APPENDIX A

DEPTH COMPUTATIONS USING PROBABILITY DISTRIBUTION

The depth computations for both FIRL/FILL and TARSLL Load Lists use probability distributions in determining the quantities. The need for the use of probability arises from the concept of Risk — the chance of running out of stock during the Support or Resupply Period. Two probability distributions are used — the Poisson and the normal. Since the normal distribution is used in most cases, we will discuss it first.

DEPTH COMPUTATION USING THE NORMAL DISTRIBUTION

Two parameters are necessary to describe a particular normal distribution. These are the mean, a measure of the average value, and the standard deviation, a measure of the spread of the distribution. An example of a general normal distribution where μ is equal to the mean and σ equal to the standard deviation.

In the normal distribution, 68 percent of all values will lie within one standard deviation of the mean ($\mu \pm \sigma$), 95.5 percent within two standard deviations ($\mu \pm 2\sigma$), and 99.75 percent within three standard deviations ($\mu \pm 3\sigma$). Looking at it another way, 16 percent of the values will be greater than $\mu + \sigma$ and 2.25 percent will be greater than $\mu + 2\sigma$.

Thus, if we wish to keep the risk of stock out to 16 percent, we should make our Load List quantity equal to $\mu + \sigma$. This means that, during the Support or Resupply Period, the probability of running out of stock is 16 percent and the probability of satisfying all the demands is 84 percent. It does <u>not</u> mean that 84 percent of all demand will be met and 16 percent will not.

The mean and standard deviation are WAD_{SP} and σ_{WD}, respectively, for the FIRL/FILL and Convential Tender Load Lists and $\bar{D}_{RP}$ and σ_{RP} for the FBM Tender Load List.

The acceptable level of risk is another essential input to the depth computations. Knowing the Risk allows us to find the t - value. We could either use an expanded version of the table shown on the next page or, as the UICP Load List operation does, use the following computations:

I. Risk less than or equal to 0.5

1. Calculate n

$$n = \sqrt{-\ln(\text{Risk}^2)}$$

ln represents the natural logarithm. A short table of these over a few values of risk is shown on the same page as the t - value. (Note: the reader is urged to use more detailed tables if exact calculations are desired.)

2. Calculate t

$$t = n - \frac{2.515517 + 0.802853n + 0.010328n^2}{1 + 1.432788n + 0.189269n^2 + 0.001308n^3}$$

II. Risk greater than 0.5

1. Calculate n

$$n = \sqrt{-\ln\left[(1 - \text{Risk})^2\right]}$$

2. Calculate t

$$t = n - \frac{2.515517 + 0.802853n + 0.010328n^2}{1 + 1.432788n + .189269^2 + 0.001308n^3}$$

Once the t - value has been found, the preliminary Load List depth can be computed.

Preliminary Depth = $\mu + t\,\sigma$

The normal distribution is used in all instances for the FIRL/FILL and Conventional Tender Load Lists and for the FBM Tender Load List when $\bar{D}_{RP}$ is greater than one unit.

t - VALUE TABLE

Risk	t
0.1	1.28
0.2	0.84
0.3	0.76
0.4	0.25
0.5	0.00
0.6	-0.25
0.7	-0.76
0.8	-0.84
0.9	-1.28

SHORT TABLE OF NATURAL LOGARITHMS

Risk	ln ($Risk^2$)
0.1	-4.605
0.2	-3.219
0.3	-2.408
0.4	-1.833
0.5	-1.386
0.6	-1.022
0.7	-0.713
0.8	-0.446
0.9	-0.211

DEPTH COMPUTATION USING THE POISSON DISTRIBUTION

The Poisson probability is used to compute the depth for FBM tenders when the expected Resupply Period Demand ($\bar{D}_{RP}$) is less than or equal to one.

The depth computation is a trial and error procedure, as follows:

1. Compute the probability that the actual demand during the Resupply Period will be for zero units

$$\text{Prob (Dmd} = 0) = e^{-\bar{D}_{RP}}$$

e is a constant and is the base of the natural logarithm. A short table of these is shown below.

$\bar{D}_{RP}$	$e^{-\bar{D}_{RP}}$
0.0	1.000
0.2	0.819
0.4	0.670
0.6	0.549
0.8	0.449
1.0	0.368

Thus, the probability that the actual demand will be for zero units, if $\bar{D}_{RP}$ is equal to 0.6, is 0.549.

2. Compare probability to Risk

If Prob (Dmd = 0) is greater than or equal to 1 — Risk, set Depth to zero.

If Prob (Dmd = 0) is less than 1 — Risk, continue to step 3.

3. Compute the probability that the actual demand is one

$$\text{Prob (Dmd = 1)} = \bar{D}_{RP} \times [\text{Prob (Dmd = 0)}]$$

In our example, the probability would be 0.6 x 0.549 = 0.329.

4. Compare probabilities to Risk

If Prob (Dmd = 0) + Prob (Dmd = 1) is greater than or equal to 1 - Risk, set Depth to one. Otherwise, continue to next step.

5. Compute the probability that the actual demand is two

$$\text{Prob (Dmd = 2)} = \bar{D}_{RP} \times \frac{[\text{Prob (Dmd = 1)}]}{2}$$

In our example, the probability would be

$$\frac{0.6 \times 3.29}{2} = 0.099$$

6. Compare probabilities to Risk

If Prob (Dmd = 0) + Prob (Dmd = 1) + Prob (Dmd = 2) is greater than or equal to 1 - Risk, set Depth to two. Otherwise, continue to next step.

7. Process continues until Depth is found.

APPENDIX B

COMPUTING UNITS SHORT

After the Risk-based Depth computed in Appendix A has been subjected to various constraints and possibly an override, the probability distributions are called on once more to compute the expected number of units short. The same probability distribution used to compute the depth is used to compute the units short.

UNITS SHORT USING THE NORMAL DISTRIBUTION

This procedure requres as input the mean demand (μ), the standard deviation of demand (σ), and the Depth which we are going to abbreviate as Z. The procedure is:

1. Calculate new t - value

$$t = \frac{Z - \mu}{\sigma}$$

2. Compute intermediate value, X

$$X = \frac{\quad}{2(1 + .196854\left|t\right| + .115194t^2 + .000344\left|t^3\right| + .019527t^4)^4}$$

3. If t is negative set X = 1 - X

4. Compute intermediate value, Y

$$Y = 0.3989e^{\frac{-t^2}{2}}$$

5. Compute intermediate value, V

$V = [Y - t \times X]\ \sigma$

6. Compare V to μ

If V is greater than or equal to μ, set Units Short to μ

If V is less than the μ, set Units Short to V

7. If computed units short is negative, set equal to zero.

UNITS SHORT USING THE POISSON DISTRIBUTION

Again, this distribution is used only with FBM tenders when the Resupply Period demand is less than or equal to one.

1. Calculate intermediate value, S

$S = \text{Depth} \times [\text{Prob (Dmd} = 0)]$

2. Set intermediate value, X, to one.

3. Compare depth to X

If Depth less than or equal to X,

Units Short $= \mu -$ Depth $+$ S

If Depth greater than X, go to Step 4.

4. Compute probability the actual demand equals X

5. Calculate intermediate value, S

S = old S + (Depth -X) Prob (Dmd = X)

6. Increase intermediate value, X, by one

X = old X + 1

7. Go to Step 3.

The procedure will continue until a Units Short computation is made.

APPENDIX C

LOAD LIST ACRONYMS

AC	Application Code
AEL	Allowance Equipage List
AFS	Combat Store Ship
APA	Appropriation Purchases Account
APL	Allowance Parts List
ARQ	Average Requisition Quantity
ASO	Aviation Supply Office
BRF	Best Replacement Factor
CARGO	Consolidated Afloat Requisitioning Guide, Overseas
CASREPT	Casualty Report
COMNAVLOGPAC	Commander, Naval Logistics, Pacific
COMSURFLANT	Commander, Surface Fleet, Atlantic
CNO	Chief of Naval Operations
DLSC	Defense Logistic Support Center
ER	Equipment Related
FBM	Fleet Ballistic Missile
FILL	Fleet Issue Load List
FIRL	Fleet Issue Requirements List
FMSO	Fleet Material Support Office
FSC	Federal Supply Classification
FSG	Federal Supply Group
LAC	Load Activity Code
3M	Maintenance and Material Management

MDF	Master Data File
MLSF	Mobile Logistic Support Force
MRU	Minimum Replacement Unit
NAVSUP	Naval Supply Systems Command
NER	Non-equipment Related
NIIN	National Item Identification Number
NMDF	Navy Management Data File
NPFC	Navy Publications and Forms Center
NSA	Navy Stock Account
PMP	Program Management Plan
POS	Peacetime Operating Stock
PWRS	Prepositioned War Reserve Stock
PSI	Program Support Interest File
RIC	Repairable Identification Code
SCA	System Constants Area
SMAR	Supply/Management Aid Record
SPCC	Ships Parts Control Center
SSPO	Strategic Systems Project Office
SSSD	Strategic Systems Support Division
TARSLL	Tender and Repair Ship Load List
TYCOM	Type Commander
U/I	Unit of Issue
UIC	Unit Identification Code
UICP	Uniform Inventory Control Point Program
WSF	Weapon Systems File

APPENDIX D

GLOSSARY

This section contains definitions of the most important words and phrases that you will encounter in the manual.

ACCEPTABLE LEVEL OF RISK

The Risk we are willing to accept of running out of stock during the Support Period. Computed by the Load List operation based on the characteristics of the item or input to the operation.

AVIATION SUPPLY OFFICE (ASO)

One of the Navy's two Inventory Control Points (ICPs). Primarily responsible for the Management of the Navy's inventory of aeronautical items.

BEST REPLACEMENT FACTOR

A fraction that describes the percent of the population of an item that can be expected to fail within a year.

CANDIDATE

An item given consideration for inclusion on a Load List.

COGNIZANCE SYMBOL (COG)

A two-position code used to identify and designate the ICP, office, or agency that exercises supply management.

COMBAT STORE SHIP (AFS)

The ship that is responsible for the surface ship resupply mission.

CONSOLIDATED AFLOAT REQUISITIONING GUIDE, OVERSEAS (CARGO)

The published Load List document for the FIRL/FILL process.

CSSR PAGE

Computer printed form that provides information reflecting the inventory position of an item.

DEMAND

The number of units of an item requested by customers in a given time period. In the Load List operation, we are only concerned with the Mobile Logistics Support Force (q.v.) demand.

DEMAND AVERAGE

A value of recurring demand that is obtained by averaging past recurring demand observations.

DEMAND FORECAST

A forecast of the demand that can be expected in some future time period. In the Load List operation, based on either the demand average (q.v.) or on a function of the Best Replacement Factor (q.v.) and the population (q.v.).

DEMAND OBSERVATION

The compilation, for a given time period, of the Mobile Logistic Support Force (q.v.) demand for an item from all customers.

DEPTH

The quantity of an item included on a load.

EAM CARD

The 80 column card used by computers.

EFFECTIVENESS

A measure of how well the load will satisfy expected demand or how well it satisfied experience demand.

ESSENTIALITY

A measure of the importance of an item to the Navy's mission.

FIRL MASTER ATLANTIC (PACIFIC) FILE

The file containing the records of the most recently constructed Atlantic (Pacific) FIRL/FILL.

FLEET ISSUE DEMAND

Demands for material from MLSF units that is placed by customer ships. Resupply demand.

FLEET ISSUE LOAD LIST (FILL)

That part of the FIRL that is deployed on a particular Combat Store Ship (q.v.) or at a designated shore base.

FLEET ISSUE REQUIREMENTS LIST (FIRL)

The range (q.v.) and depth (q.v.) of material required to support the Fleet (Atlantic or Pacific) under a projected wartime environment for a designated period of time.

FLEET MATERIAL SUPPORT OFFICE (FMSO)

NAVSUP's computer support and systems analysis organization. Responsible for the design and development of the computer programs of the UICP system and managing the Load List operation.

FLEET SUPPORT FACTOR

Demand multiplier representing the increased tempo of operations expected during wartime. Used in FIRL/FILL process.

INDUSTRIAL DEMAND

Demand originating from the industrial shops of tenders, repair ships, and support detachments. Results from work performed for supported fleet units.

INVENTORY CONTROL POINT (ICP)

An organizational unit or activity that is assigned primary responsibility for the supply management of a group of items.

LOAD LIST MASTER FILE

A separate file is made for each TARSLL and contains the records of the most recently constructed load.

MASTER DATA FILE (MDF)

The file that contains information about the characteristics--management data, asset position, requirements, levels, and forecasts--of those items managed by an ICP.

MLSF Master Demand File

The file containing the record of MLSF demands for the most recent 24 months.

MOBILE LOGISTIC SUPPORT FORCE (MLSF)

The ships and selected shore activities that have responsibility for providing the Operating Forces with resupply and repair support. Consists of Combat Store Ships, Destroyer Tenders, Submarine Tenders, Repair Ships, and selected shore activities.

NATIONAL ITEM IDENTIFICATION NUMBER (NIIN)

An identifying number for inventory items.

NATIONAL STOCK NUMBER (NSN)

An identifying number for inventory items. Includes the NIIN.

NAVY MANAGEMENT DATA FILE (NMDF)

The file containing management data for items reflecting Navy interest as registered in the Federal Cataloging Program.

NMDF ADDENDUM FILE

Cross references superceded NIINs to current NIINs.

PROBABILITY

The measure of the likelihood that an event will occur.

PROGRAM SUPPORT INTEREST (PSI) FILE

The file containing information relative to items for which the ICP has Program Support responsibilities but another ICP or DSC has Supply Support responsibilities.

RANGE

The variety of items on a load.

SHIPS PARTS CONTROL CENTER (SPCC)

One of the Navy's two Inventory Control Points (ICPs). Primarily responsible for the management of the Navy's inventory of non-aeronautical items.

SKIM LISTING

Preliminary output of TARSLL process. Used for review.

STANDARD DEVIATION

A measure of the variability of observations. The square root of the variance (q.v.).

SUPPLY/MANAGEMENT AID RECORD (SMAR)

A record prepared for each item on a load contains management data and quantities.

SUPPORT PERIOD

Length of time load is expected to support Fleet requirements.

TECHNICAL OVERRIDES

Manual inputs that can be used to add or exclude items from the range of a Load List and to increase or decrease the computed depth for an item.

TEMPO FACTOR

Demand multiplier representing the increased tempo of operations expected during wartime. Used in the TARSLL process.

TENDER AND REPAIR SHIP LOAD LIST (TARSLL)

The load representing the projected material requirements for the repair missions of Destroyer Tenders and Repair Ships and the repair and resupply missions of Submarine Tenders.

TOTAL PARTS POPULATION

The total number of a particular item in the system.

UNIT COST

The cost of one unit of an item.

UNIT IDENTIFICATION CODE (UIC)

A six-position code that identifies a specific ship or shore activity. It is composed of a five-digit numeric UIC/Accounting Number preceded by an alpha "R" for a ship or an alpha "N" for a shore station, retrofit activity, etc.

UNIT OF ISSUE (U/I)

The quantity in which an item is distributed: pound, foot piece, barrel, etc.

UNIFORM INVENTORY CONTROL PROGRAM (UICP)

The Navy's automated inventory control system for ICPs.

<u>VARIANCE</u>

A measure of the variability of observations. Calculated by taking the average of the squared deviations of the observations from the expected value.

<u>WEAPON SYSTEM FILE (WSF)</u>

The file containing information about an end use weapon broken down into systems, subsystems, equipments, components, sub-components, and parts.

APPENDIX E

INDEX

FBM TLL MODEL ANALYSIS

VITRO (MSE) 10 January 1977

During October, 1976 Vitro personnel in conjunction with SP 206 attended at FMSO a presentation on the math model to be developed for FBM TLL production. The data used for determining the math model was AS-31 demands during a period when only two (2) SSBNs were supported and was judged inadequate by SSPO. A more-in depth study was requested by SSPO and FMSO is scheduled to deliver this study in the near future (FMSO TELECON) for SSPO (SP-206) evaluation.

The following is MSB's comments on the "Normal-Poisson" math model proposed by FMSO during the October 1976 presentation and Vitro (MSB)'s recommendations for TLL model improvement.

I. TLL GOAL

The goal of an effective TLL model is to provide a maximum predicted protection level at a minimum stocking level/cost. The FMSO is currently planning on developing a 25,000 item TLL with a 98% (2 siginificant digit) predicted protection level at a cost of 3 million dollars. Previous studies of the FMSO TLL on-site operational performance indicate the model performs considerably less efficient than predicted. The purpose of this paper is to analyze TLL production procedures and recommend parameters for an improved TLL model.

II. DEMAND/FREQUENCY DATA ANALYSIS

VITRO (MSB) under the direction of SP20603 (LCDR. P. Berger) has reviewed site I, II, and IV demand/frequency data (see attachment 1). The study highlights that 1,000 items, of which 95% are consumables, supported 39% of the demand frequencies for the combined sites. An additional 1,000 items provided an additional 13% support. By assuring these items are stocked, a 52% "baseline" TLL support effectiveness is readily obtained. The need for an additional 23,000 items to obtain a 98% predicted protection level is questionable.

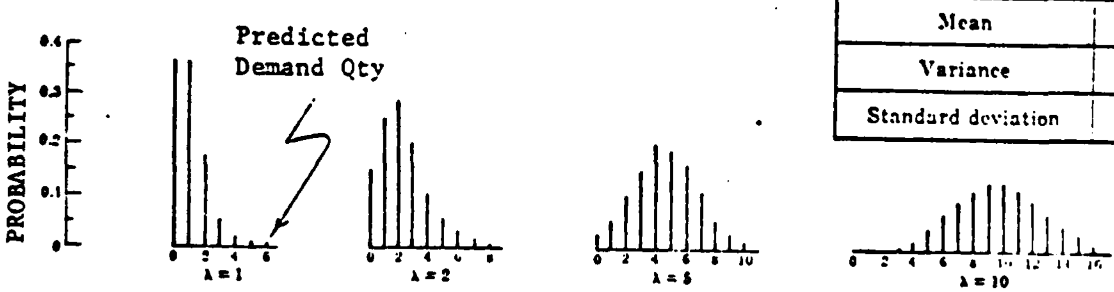
III. DEMAND/FREQUENCY DATA DISTRIBUTION PATTERNS

In analyzing site I, II, and IV demand/frequency data, the following pattern is noted. Consumable items, with high frequencies and demand quantities, will compute to a high mean quantity (λ) and therefore are normally distributed. Equipment related items, in comparison to consumable items, experience low frequencies and demand quantities. The demand pattern for equipment related items tends to shift away from the mean (lots of qty<2 in comparison with qty >2) and the computed λ is small.

The probability distribution pattern for equipment related items is not normal, but follows the Poisson pattern (see below). The Poisson distribution pattern approaches the normal pattern where λ =5. A "quick look" at VITRO (MSB) demand data indicates that a Poisson Distribution with λ=1-2 most closely simulates FBM equipment related item demands.

POISSON DISTRIBUTIONS

Poisson distribution	
Mean	$\mu = \lambda$
Variance	$\sigma^2 = \lambda$
Standard deviation	$\sigma = \sqrt{\lambda}$



Poisson distribution for selected values of λ

IV. CURRENT FMSO TLL PRODUCTION PROCEDURES

The current TLL production procedures, in general, are as follows (MSB belief):

A. TLL candidates are selected and a predicted demand quantity is computed based upon (BRF x POP) data

B. Demand data (most current 2 years) for FBM Tender and assigned SSBN hull mix is matched versus the "selected" TLL candidates

1. Where no match occurs, the item with demand is added to the TLL

2. Where a match occurs the demand quantity replaces the predicted BRF x POP demand quantity.

V. PROBLEM AREAS

A. Unstable Load Quantities

The action of replacing predicted demand with actual demand based upon a 2 year statistical sample results in an unstable loading factor for individual items as shown below:

TLL DOC	ITEM	LOAD QTY	FLEET DEMAND
1	A	5 (BRF x POP)	0 (1st 2 yr sample)
2	A	1 (DEMAND DATA)	1 (2nd 2 yr sample)
3	A	5 (BRF x POP)	0 (3rd 2 yr sample)

Item A is continuously onloaded/offloaded. Because of this condition, deployed Tenders are dependent upon the previous on-site Tender's demand data to adjust their MRF to "true" operational stocking levels.

When applying the demand data to their MRF, many items must also be added due to exclusion from the new TLL. Since all demanded items are added in the FMSO TLL production procedure, problems exist in the current demand recording/ implementation loop.

B. Demand Recording Interval

Where a statistical sample is used to predict, the predictions will vary because the statistical sample will vary. For example, FBM usage data will vary based upon

failure rates, SSBNs supported during the selected interval, etc. If the observance interval were extended from the current 2 year (8 quarter) period to the previous Tender's deployment span, a more accurate sample, particularly for equipment related items, would result. SP206/VITRO recorded SSBN SRB and ACCESS data could be made available to the FMSO for this purpose.

C. BRF Updates

The validity of the predicted demand quantity is dependent upon frequent updating of the BRF values with FBM oriented usage data (last accomplished 2 years ago). Historically, only 15-20% of a Tender's stocked items experience demands, therefore the mean value (λ) computation is significantly based upon prediction data (BRF x POP). Actual fleet demand data plays an almost insignificant role in the FMSO mean value computation. Significant numbers to be obtained from FMSO prior to selecting a TLL production model are:

1. Number of predicted demand quantities replaced by actual demand quantities (greater and less)

2. Number of items, that were not candidates, added due to actual demand

If the percentage of of "demand effected" items in the TLL is significantly small, the value of using fleet demand data in the model, except for BRF updating, is questionable. The probability distribution curve will be based, 90% or greater, on prediction data not fleet demand data.

D. Determination of Probability Distribution Curve

The following are some different methods which maybe used to compute λ for probability distribution curve selection.

1. Combine prediction data and fleet demand data for both equipment related and consumable items to compute λ. Where $\lambda < 1$ use Poisson Distribution and where $\lambda > 1$ use a Normal Distribution (MSB belief to be current FMSO procedure). This procedure has the following disadvantages.

a. apples (prediction data) and oranges (statistical sampling of actual FBM demand) are being mixed to determine λ. This is somewhat accetable if BRF is frequently updated (not current procedure).

b. consumable items demand result in large λ

c. large λ results in Normal Distribution and more equipment related items (high cost and limited quantities in FBM Program) being stocked than required

2. Extract consumable items and compute λ based upon statistical sampling of FBM demand data for equipment related items only. A Poisson distribution will result (λ small). Smaller quantities of equipment related items will be stocked for maximum protection level.

3. Extract consumable items, and use prediction data (BRF x POP) to compute λ . FBM demands (less than 20% of range of prediction data) would be used to update BRF values and prediction quantities where required. This value of λ will be dependent upon BRF x POP prediction quantities. A Normal to Poisson switchover maybe required due to varying λ and stocking quantities will vary.

Other combinations exist, and it is recommended that SSPO (SP206) study the impact of the different procedures prior to selecting parameters for a probability distribution curve.

VI. RECOMMENDED PARAMETERS FOR AN IMPROVED TLL MODEL

The following are VITRO (MSB)'s recommendations for an improved TLL model:

A. Extract consumable items from TLL computations and develop a "Consumable Item Section" that:

1. Makes use of consumable item commonality

2. Will result in a lower mean value (λ) computation for equipment relateu items

B. Frequently update BRF with FBM oriented usage data.

C. Expand statistical sample of frequency demand data period from 2 years to on-site deployment span of relieved Tender.

D. Replace predicted values with FBM demand quantities only where fleet demand predicted value.

E. Use Poisson Probability Distribution curve for equipment related items; eliminate switchover to Normal Distribution in the TLL model.

Recommendation E is based upon the belief that λ for equipment related items is small (less than 5 where Normal and Poisson distributions equate). To verify or disprove this assumption it is recommended that VITRO (MSB) plot statistical sample of equipment related item

frequency demand data for varied operational periods of 2, 3, and 4 years for site I, II, and IV Tenders. The data available in the usage segment of the FUDAS record (see attachment 2 for AS-33 data available) would be displayed in attachment 3 format. The graphical displays would provide a firm basis for an SSPO (SP206) decision to use or not use the Poisson Distribution without switchover to a Normal Curve in the TLL model. The Normal Distribution results in stocking greater on board quantities for λ than the Poisson Distribution in the TLL Model (see attachment 4) to obtain an equal protection level.

VIII. ADVANTAGES OF RECOMMENDED CHANGES

The proposed revisions to the TLL model should provide the following improvements:

A. A TLL more oriented to actual on-site requirements at reduced stocking levels/cost.

1. Poisson Distribution used for equipment related items

2. Consumable items will be stocked using "Consumable Stocking List" that:

a. is based upon "proven periodic needs" versus prediction data and statistical sampling of demand data

b. makes use of commonality of consumable demand for all Tender sites.

B. Frequent FBM oriented update of BRF will result in more accurate prediction data.

C. Expanded period of FBM frequency demand data observance should result in a more accurate picture of equipment related item demands and reduce instability of stocking quantities currently existing.

D. Simplification of the TLL model should result in improved production schedules, stock numbers become "OLD" during current production interval.

SITE I[illegible] I, AND IV

DEMAND FREQUENCY ANALYSIS

Prepared by SP 20603

	I/32	II/33	IV/31	TOTAL
COMMON NIIN	9588	9588	9588	9588
PECULIAR NIIN	4300	4300		4300
PECULIAR NIIN	3710		3710	3710
PECULIAR NIIN		3410	3410	3410
UNIQUE NIIN	11282	11046	8430	30758
TOTAL	28880	28344	25138	51766
FREQ	206278	188082	140487	534847

TOP 1000 NIINs (1.93%) account for 210729 freqs (39%)

TOP 1803 NIINs (3.48%) account for 267424 freqs (50%)

TOP 2000 NIINs (3.86%) account for 278120 freqs (52%)

Demand analysis of Top 1000

961 were common

36 were peculiar

3 were unique

AT 4 analysis of Top 1000

Site I	357	(35.7%)
Site II	117	(11.7%)
Site IV	284	(28.4%)
	758	(25.4%

NOTE: Bulk are 90 followed by 9G, 9D, 1I, 9L; less than 5% are other cogs

Attachment 1

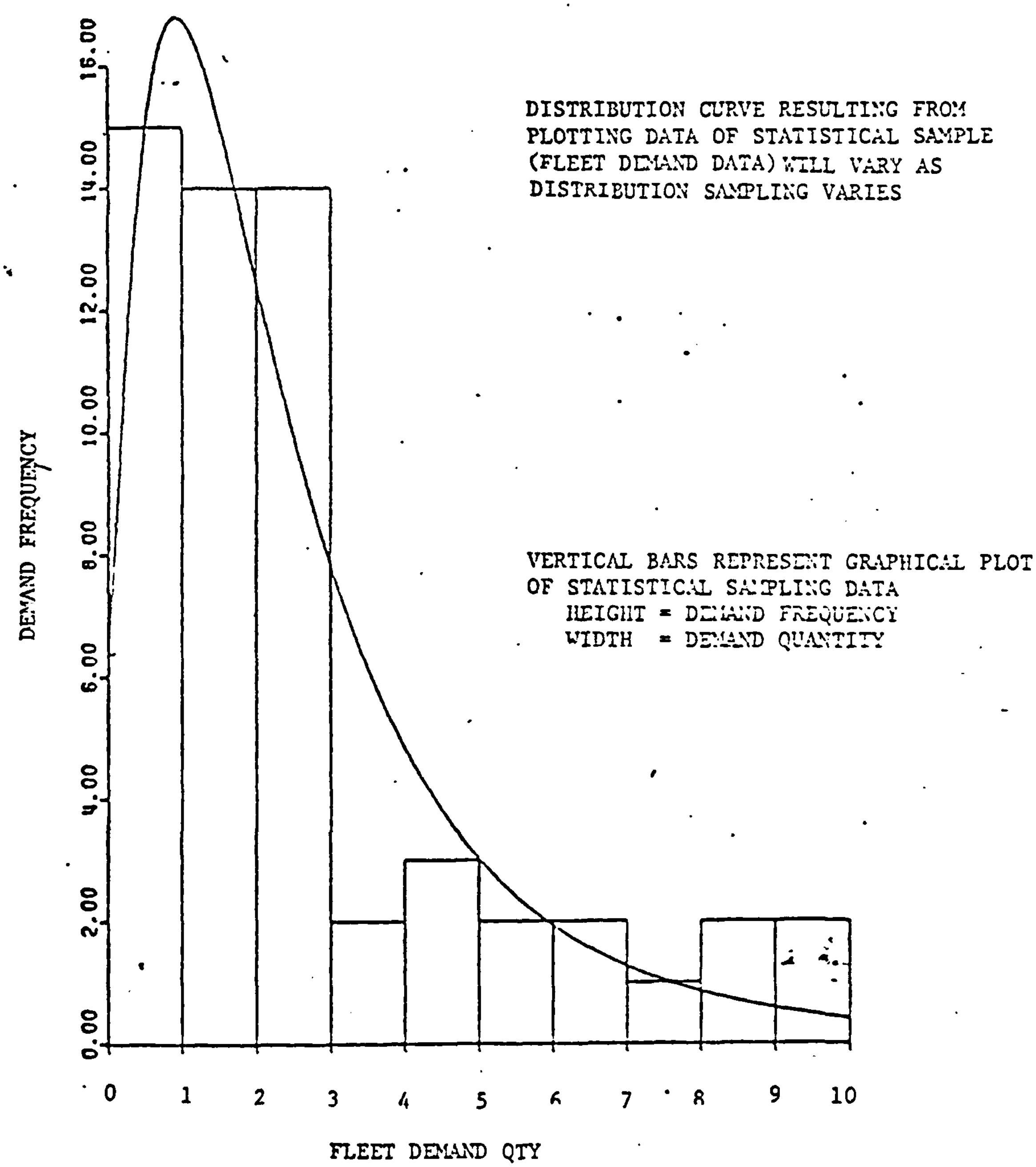
BREAKDOWN OF AS-33 HULL MIX

SSBN	HULL COUNT	*RECORDED DEMANDS (ITEM/APL)
640	25,289	7,413
641	25,587	7,020
642	23,421	6,409
643	25,486	7,023
644	25,060	7,447
645	24,917	5,775
654	25,050	5,922
655	22,364	5,756
656	25,223	6,531
657	24,634	4,480

* Vitro maintains a unique ADP record for each SSBN/Stock number/APL number demand reported via the ACCESS data.

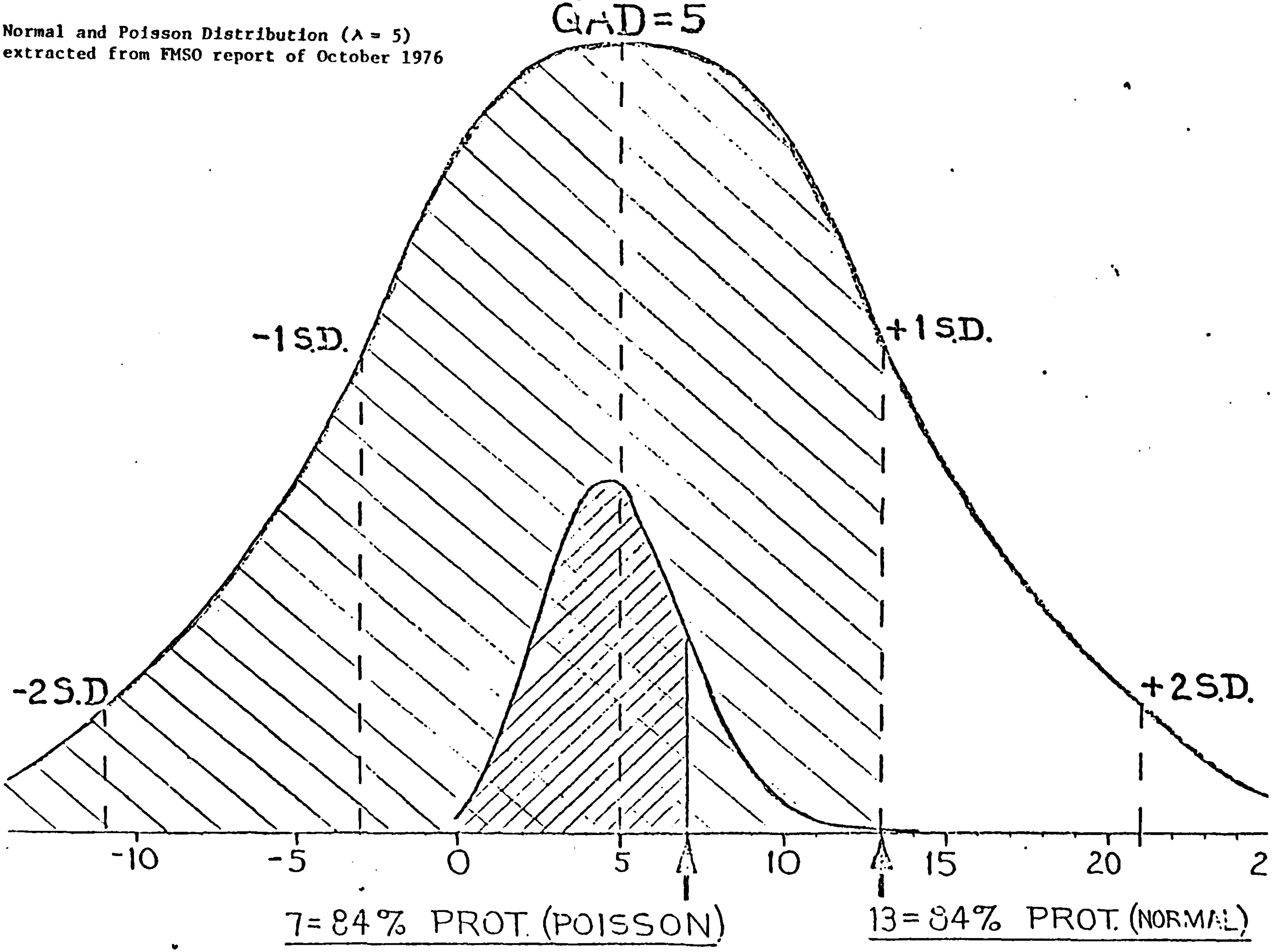
Attachment 3

DETERMINATION OF DISTRIBUTION CURVE



A. ɿent 4

Normal and Poisson Distribution ($\lambda = 5$)
extracted from FMSO report of October 1976



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DEPARTMENT OF THE NAVY
NAVY FLEET MATERIAL SUPPORT OFFICE
MECHANICSBURG, PA. 17055

AREA CODE 717
766-8311 EXT.
AUTOVON 277 & EXT. 3641

IN REPLY REFER TO:
971237/WWK/100
5250

MAY 26 1977

From: Commanding Officer, Navy Fleet Material Support Office
To: Director, Strategic Systems Project Office

SP 206
3A

Subj: FBM Tender Load List Quantities

Ref: (a) SSPO ltr 206/REC/953 of 21 Jul 1975
(b) FMSO ltr 971237/WWK/18 5250 of 3 Feb 1977

Encl: (1) ALRAND Working Memorandum 304 - FBM Load List Prediction Model

1. Reference (a) requested development of a method for accurately estimating FBM (Fleet Ballistic Missile) load list quantities at time of provisioning. A study description of a proposed method was forwarded by reference (b). The study has been completed and results are forwarded as enclosure (1).

2. Tables have been developed for guidance of the technician during provisioning of hull, mechanical, electrical, electronic and ordnance items. The tables are based on policies currently incorporated in the approved tender load list model. It is expected that provisioning decisions should closely approximate later load list determinations.

R. W. ST. MARTIN
By direction

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971237/WWK
20 May 1977

ALRAND Working Memorandum 304

Subj: FBM Load List Prediction Model

Ref: (a) Operations Analysis Study Report 127 - FBM Load List Study of 31 Dec 1976
(b) ALRAND Working Memorandum 195 - Load List Standard Deviation Approximation of 3 Mar 1970

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1. Purpose. Develop a formula for use during the provisioning of SSBN hull, mechanical, electrical, electronic, or ordnance equipments to provide tender load list quantities.

2. Background. Technicians determine the range and depth of new investment and repairable items to be added to the tender load lists supporting hulls/equipments being provisioned. Guidance on these determinations has not been coordinated with policies employed in TLL (tender load list) computation models. As a result, subsequent execution of the model computes quantities which vary with original provisioning quantities and excesses/shortages are made manifest. Provisioning technicians need an equation or tables to determine range and depth of items that will be in agreement with later load list determinations.

3. Approach. Reference (a) describes the model incorporating approved policy for determination of load list quantities for FBM. Salient features of the model are summarized as follows:

a. Demand Distribution. Item demand is described by either the Poisson or Normal distribution. The Poisson distribution is assumed to be descriptive where the forecasted QAD (Quarterly Average Demand) is one or less. The Normal distribution is assumed where the QAD is greater than one.

b. Demand History. For items with demand history, the QAD is based on the latest two years of recorded demand. Where no demand history exists for the item, the QAD is the product of the BRF (Best Replacement Factor) and the population to be supported divided by four.

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c. Model Characteristics. The optimization model minimizes demand-weighted requisitions short. It is a variable protection model considering unit price, the average requisition size and QAD for the item. The protection level by item is constrained to be a minimum of 1% and a maximum of 99%. Further constraints are applied to items with no demand history. The maximum allowed depth is 50 units or $100 unless exceeded by the minimum replacement unit. Model goals are a minimum of 95% net effectiveness and an 85% gross effectiveness is desired.

d. Model Application. The production load for the AS33 and test loads for the AS31 were developed with the approved model. TABLE I shows item distribution based on unit price and QAD for the AS31. The same data is presented in TABLE II for the AS33. By observation, approximately 90% of the load items have unit prices below $100, also approximately 85% of the items have a QAD of 1.00 or less. TABLES III and IV show distribution of number of items by price categories, and TABLES V and VI show distribution of items by QAD.

4. Results. Using the techniques and principles inherent to the approved model, tables were developed for use in the provisioning process. The risk control parameter for loads developed to date has been set equal to 0.00035 and was used to develop these tables. Where historical data was lacking, the average requisition size was assumed equal to one.

TABLE VII shows predicted tender load list quantities without constraints. If the depth constraint of 50 units and/or $100 is applied, then the predicted quantities are shown in TABLE VIII. The line across TABLE VIII indicates the threshold where the constraints become active. TABLES VII and VIII are identical for entries above the line. It is estimated that approximately 90% of the items provisioned will have unit prices and QADs that are found above the line in TABLE VIII.

To use the table, the provisioner would need to know the unit price of the item and the forecasted QAD. The

predicted tender load list quantity would be selected from the appropriate table. Examples: (1) Given: Item unit price = $40 and forecasted QAD = 1.25 (based on historical demand). Solution: Go to TABLE VII, at intersection of $40 column and QAD row of 1.25, read predicted load quantity = 6 units; (2) Given: Item unit price = $40 and forecasted QAD = 1.25 (based on BRF and installed population). Solution: Go to TABLE VIII, at intersection of $40 column and 1.25 QAD row, read predicted load quantity = 2 units.

5. Discussion. TABLES VII and VIII will give accurate results in predicting load quantities so long as the model policies remain constant and the candidate file remains representative. This assumes proper application of the tables (TABLE VII for items with a demand history and TABLE VIII for other items) and accurate data is used for selecting load quantity. Should the provisioner select the wrong table, the result will still be accurate in 92% of the cases. If the unit price of the item was estimated at time of provisioning and later changed, then the predicted quantity will be in error. The same applies to the value of QAD. A significant change in the characteristics of the candidate file would require a new risk control parameter to attain the desired goals.

To illustrate the latter point, assume conditions require the risk control parameter to be reduced to 0.00001. TABLE IX shows the unconstrained predicted values for the load and TABLE X shows the predicted quantities where the constraints apply. Using the same entry parameters as in our previous examples, now the predicted quantity for a demand-based item is still six units, and the constrained quantity is still two units. The numbers in parenthesis indicate the impact of the change due to the risk control parameter and were obtained by comparing quantities to TABLES VII and VIII. The impact of raising the risk control parameter from 0.00035 to 0.005 is shown in TABLES XI and XII for the unconstrained and constrained situations, respectively. Again, the numbers in parenthesis show changes from the predicted load quantities based on the current risk control parameter.

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6. Conclusions and Recommendations. It is expected that predicted load list quantities calculated at time of provisioning will closely approximate quantities later computed by the model. Changes of unit prices and of QADs from time of provisioning to actual load computation, will produce variances in load quantities. Changes in characteristics of the candidate file, if radical, will necessitate a new risk control parameter and recomputation of the tables for use in provisioning prediction.

To simplify the predicting process, TABLES XIII and XIV have been prepared. The lower range of QAD has been expanded and unit price ranges have been introduced to reduce the columns of the table.

It is recommended that TABLES XIII and XIV be used for load list quantity prediction at time of provisioning.

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TABLE I

AS31 CANDIDATE FILE ITEM DISTRIBUTIONS
(BY PERCENTAGE OF TOTAL CANDIDATES)

QUARTERLY DEMAND	UNIT PRICE					
	0-1	1-5	5-25	25-100	100-1000	SUB-TOTALS
0- .05	18.95	13.94	11.88	4.64	3.64	53.05
.05- .10	2.89	2.79	2.16	1.31	1.25	10.40
.10- .50	5.49	4.95	4.27	2.85	2.65	20.21
.50-1.00	1.82	1.30	1.05	0.63	0.54	5.34
1.00-5.00	2.79	1.58	1.12	0.64	0.44	6.57
5.00-100	1.54	0.49	0.27	0.08	0.05	2.43
100-1000	0.11	0.03	0.00	0.00	0.00	0.14
SUB-TOTALS	33.59	25.08	20.75	10.15	8.57	98.14[1]

TABLE II

AS33 CANDIDATE FILE ITEM DISTRIBUTIONS
(BY PERCENTAGE OF TOTAL CANDIDATES)

QUARTERLY DEMAND	UNIT PRICE					
	0-1	1-5	5-25	25-100	100-1000	SUB-TOTALS
0- .05	15.29	13.91	11.78	4.65	4.01	49.64
.05- .10	2.53	2.82	2.56	1.39	1.40	10.70
.10- .50	4.92	5.34	4.57	3.14	3.01	20.98
.50-1.00	1.69	1.49	1.24	0.73	0.67	5.82
1.00-5.00	2.58	1.82	1.34	0.84	0.57	7.15
5.00-100	1.66	0.67	0.38	0.17	0.07	2.95
100-1000	0.15	0.04	0.02	0.00	0.00	0.21
SUB-TOTALS	28.82	26.09	21.89	10.92	9.73	97.45[2]

[1] Does not include 954 items that had either a predicted QAD > 1000 or unit price > 1000

[2] Does not include 1439 items that had either a predicted QAD > 1000 or unit price > 1000

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TABLE III

AS31: NUMBER OF ITEMS BY CATEGORY OF UNIT PRICE

UNIT PRICE CATEGORY	NR. OF ITEMS	% OF TOTAL	CUMULATIVE NR. OF ITEMS	CUM %
0.00- 1.00	17,323	.33.59	17,323	33.59
1.00- 5.00	12,926	25.08	30,249	58.67
5.00- 25.00	10,696	20.75	40,945	79.42
25.00- 100.00	5,233	10.15	46,178	89.57
100.00-1000.00	4,420	8.57	50,598	98.14
SUB-TOTAL	50,598			
Items w/demand > 1000	3			
Items w/unit price > 1000	951		51,552	100.00
TOTAL	51,552			

TABLE IV

AS33: NUMBER OF ITEMS BY CATEGORY OF UNIT PRICE

UNIT PRICE CATEGORY	NR. OF ITEMS	% OF TOTAL	CUMULATIVE NR. OF ITEMS	CUM %
0.00- 1.00	16,295	28.82	16,295	28.82
1.00- 5.00	14,743	26.09	31,038	54.91
5.00- 25.00	12,371	21.89	43,409	76.80
25.00- 100.00	6,171	10.92	49,850	87.72
100.00-1000.00	5,498	9.73	55,078	97.45
SUB-TOTAL	55,078			
Items w/demand > 1000 / Items w/unit price > 1000	1,439		56,517	100.00
TOTAL	56,517			

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TABLE V

AS31: NUMBER OF ITEMS BY CATEGORY OF PREDICTED QUARTERLY AVG DEMAND

AVERAGE DEMAND CATEGORY	NR. OF ITEMS	% OF TOTAL	CUMULATIVE NR. OF ITEMS	CUM %
0.00- 0.05	27,345	53.05	27,345	53.05
0.05- 0.10	5,358	10.40	32,703	63.45
0.10- 0.50	10,420	20.21	43,123	83.66
0.50- 1.00	2,751	5.34	45,874	89.00
1.00- 5.00	3,388	6.57	49,262	95.57
5.00- 100.00	1,261	2.43	50,523	98.00
100.00-1000.00	75	0.14	50,598	98.14
SUB-TOTAL	50,598			
Items w/demand > 1000	3		50,601	
Items w/unit price > 1000	951		51,552	100.00
TOTAL	51,552			

TABLE VI

AS33: NUMBER OF ITEMS BY CATEGORY OF PREDICTED QUARTERLY AVG DEMAND

AVERAGE DEMAND CATEGORY	NR. OF ITEMS	% OF TOTAL	CUMULATIVE NR. OF ITEMS	CUM %
0.00- 0.05	28,053	49.64	28,053	49.64
0.05- 0.10	6,048	10.70	34,101	60.34
0.10- 0.50	11,858	20.98	45,959	81.32
0.50- 1.00	3,290	5.82	49,249	87.14
1.00- 5.00	4,042	7.15	53,291	94.29
5.00- 100.00	1,669	2.95	54,960	97.24
100.00-1000.00	118	0.21	55,078	97.45
SUB-TOTAL	55,078			
Items w/demand > 1000 / Items w/unit price > 1000	1,439		56,517	100.00
TOTAL	56,517			

TABLE VII

PREDICTED TENDER LOAD LIST QUANTITY
(QUANTITY UNCONSTRAINED)

DEMAND	1.00	2.00	3.00	5.00	8.00	10.00	15.00	20.00	25.00	30.00	35.00	40.00	45.00	50.00	100.00	1000.00
	UNIT PRICE IN DOLLARS															
0.05	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0
0.10	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0
0.20	2	2	2	2	2	2	1	1	1	1	1	1	1	1	1	0
0.30	2	2	2	2	2	2	2	2	2	2	1	1	1	1	1	0
0.40	2	2	2	2	2	2	2	2	2	2	2	2	2	2	1	0
0.50	3	3	3	3	3	3	3	3	2	2	2	2	2	2	2	0
0.60	3	3	3	3	3	3	3	3	3	3	3	2	2	2	2	0
0.70	3	3	3	3	3	3	3	3	3	3	3	3	3	3	2	1
0.80	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	1
0.90	4	4	4	4	4	4	4	4	4	4	3	3	3	3	3	1
1.00	4	4	4	4	4	4	4	4	4	4	4	4	4	4	3	1
1.25	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	3
1.50	8	8	8	8	8	8	8	8	8	8	8	8	8	7	7	4
1.75	9	9	9	9	9	9	9	9	9	9	9	9	9	9	8	5
2.00	10	10	10	10	10	10	10	10	10	10	10	10	10	10	9	5
3.00	15	15	15	15	15	15	15	15	15	15	15	15	15	15	14	9
4.00	19	19	19	19	19	19	19	19	19	19	19	19	19	19	19	13
5.00	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	17
10.00	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	39
20.00	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	38
30.00	142	142	142	142	142	142	142	142	142	142	142	142	142	142	142	139
40.00	189	189	189	189	189	189	189	189	189	189	189	189	189	189	189	189
50.00	237	237	237	237	237	237	237	237	237	237	237	237	237	237	237	237
100.00	473	473	473	473	473	473	473	473	473	473	473	473	473	473	473	473
1000.00	4723	4723	4723	4723	4723	4723	4723	4723	4723	4723	4723	4723	4723	4723	4723	4723

TABLE VIII

PREDICTED TENDER LOAD LIST QUANTITY
(QUANTITY CONSTRAINED)

	UNIT PRICE IN DOLLARS															
DEMAND	1.00	2.00	3.00	5.00	8.00	10.00	15.00	20.00	25.00	30.00	35.00	40.00	45.00	50.00	100.00	1000.00
0.05	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0
0.10	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0
0.20	2	2	2	2	2	2	1	1	1	1	1	1	1	1	1	0
0.30	2	2	2	2	2	2	2	2	2	2	1	1	1	1	1	0
0.40	2	2	2	2	2	2	2	2	2	2	2	2	2	2	1	0
0.50	3	3	3	3	3	3	3	3	2	2	2	2	2	2	1	0
0.60	3	3	3	3	3	3	3	3	3	3	2	2	2	2	1	0
0.70	3	3	3	3	3	3	3	3	3	3	2	2	2	2	1	1
0.80	3	3	3	3	3	3	3	3	3	3	2	2	2	2	1	1
0.90	4	4	4	4	4	4	4	4	4	3	2	2	2	2	1	1
1.00	4	4	4	4	4	4	4	4	4	3	2	2	2	2	1	1
1.25	6	6	6	6	6	6	6	5	4	3	2	2	2	2	1	1
1.50	8	8	8	8	8	8	6	5	4	3	2	2	2	2	1	1
1.75	9	9	9	9	9	9	6	5	4	3	2	2	2	2	1	1
2.00	10	10	10	10	10	10	6	5	4	3	2	2	2	2	1	1
3.00	15	15	15	15	12	10	6	5	4	3	2	2	2	2	1	1
4.00	19	19	19	19	12	10	6	5	4	3	2	2	2	2	1	1
5.00	24	24	24	20	12	10	6	5	4	3	2	2	2	2	1	1
10.00	48	48	33	20	12	10	6	5	4	3	2	2	2	2	1	1
20.00	50	50	33	20	12	10	6	5	4	3	2	2	2	2	1	1
30.00	50	50	33	20	12	10	6	5	4	3	2	2	2	2	1	1
40.00	50	50	33	20	12	10	6	5	4	3	2	2	2	2	1	1
50.00	50	50	33	20	12	10	6	5	4	3	2	2	2	2	1	1
100.00	50	50	33	20	12	10	6	5	4	3	2	2	2	2	1	1
1000.00	50	50	33	20	12	10	6	5	4	3	2	2	2	2	1	1

Line across table indicates point at which constraints become active.

TABLE IX

PREDICTED TENDER LOAD LIST QUANTITY
(QUANTITY UNCONSTRAINED)

	UNIT PRICE IN DOLLARS															
DEMAND	1.00	2.00	3.00	5.00	8.00	10.00	15.00	20.00	25.00	30.00	35.00	40.00	45.00	50.00	100.00	1000.0(
0.05	1	1	1	1	1(-1)	1(-1)	1(-1)	1(-1)	1(-1)	1(-1)	1(-1)	1(-1)	1(-1)	1(-1)	1(-1)	0
0.10	1	1	1	1	1	1	1	1	1	1(-1)	1(-1)	1(-1)	1(-1)	1(-1)	1(-1)	0
0.20	2	2	2	2	2	2	2(-1)	2(-1)	2(-1)	2(-1)	2(-1)	2(-1)	2(-1)	2(-1)	2(-1)	1(-
0.30	2	2	2	2	2	2	2	2	2	2	2(-1)	2(-1)	2(-1)	2(-1)	2(-1)	2(-
0.40	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2(-1)	2(-
0.50	3	3	3	3	3	3	3	3	3(-1)	3(-1)	3(-1)	3(-1)	3(-1)	3(-1)	3(-1)	2(-
0.60	3	3	3	3	3	3	3	3	3	3	3	3(-1)	3(-1)	3(-1)	3(-1)	3(-
0.70	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3(-1)	3(-
0.80	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3(-
0.90	4	4	4	4	4	4	4	4	4	4	4(-1)	4(-1)	4(-1)	4(-1)	4(-1)	4(-
1.00	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4(-1)	4(-
1.25	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6(-
1.50	8	8	8	8	8	8	8	8	8	8	8	8	8	8(-1)	8(-1)	8(-
1.75	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9(-1)	9(-
2.00	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10(-1)	10(-
3.00	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15(-1)	15(-
4.00	19	19	19	19	19	19	19	19	19	19	19	19	19	19	19	19(-
5.00	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24(-
10.00	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48(-3
20.00	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95(-7
30.00	142	142	142	142	142	142	142	142	142	142	142	142	142	142	142	142(-3
40.00	189	189	189	189	189	189	189	189	189	189	189	189	189	189	189	189
50.00	237	237	237	237	237	237	237	237	237	237	237	237	237	237	237	237
100.00	473	473	473	473	473	473	473	473	473	473	473	473	473	473	473	473
1000.00	4723	4723	4723	4723	4723	4723	4723	4723	4723	4723	4723	4723	4723	4723	4723	4723

TABLE X

PREDICTED TENDER LOAD LIST QUANTITY
(QUANTITY CONSTRAINED)

UNIT PRICE IN DOLLARS

DEMAND	1.00	2.00	3.00	5.00	8.00	10.00	15.00	20.00	25.00	30.00	35.00	40.00	45.00	50.00	100.00	1000.00
0.05	1	1	1	1(-1)	1(-1)	1(-1)	1(-1)	1(-1)	1(-1)	1(-1)	1(-1)	1(-1)	1(-1)	1(-1)	1(-1)	0
0.10	1	1	1	1	1	1	1	1	1	1(-1)	1(-1)	1(-1)	1(-1)	1(-1)	1(-1)	0
0.20	2	2	2	2	2	2	2(-1)	2(-1)	2(-1)	2(-1)	2(-1)	2(-1)	2(-1)	2(-1)	1	1(-1)
0.30	2	2	2	2	2	2	2	2	2	2	2(-1)	2(-1)	2(-1)	2(-1)	1	1(-1)
0.40	2	2	2	2	2	2	2	2	2	2	2	2	2	2	1	1(-1)
0.50	3	3	3	3	3	3	3	3	3(-1)	3(-1)	2	2	2	2	1	1(-1)
0.60	3	3	3	3	3	3	3	3	3	3	2	2	2	2	1	1(-1)
0.70	3	3	3	3	3	3	3	3	3	3	2	2	2	2	1	1
0.80	3	3	3	3	3	3	3	3	3	3	2	2	2	2	1	1
0.90	4	4	4	4	4	4	4	4	4	3	2	2	2	2	1	1
1.00	4	4	4	4	4	4	4	4	4	3	2	2	2	2	1	1
1.25	6	6	6	6	6	6	6	5	4	3	2	2	2	2	1	1
1.50	8	8	8	8	8	8	6	5	4	3	2	2	2	2	1	1
1.75	9	9	9	9	9	9	6	5	4	3	2	2	2	2	1	1
2.00	10	10	10	10	10	10	6	5	4	3	2	2	2	2	1	1
3.00	15	15	15	15	12	10	6	5	4	3	2	2	2	2	1	1
4.00	19	19	19	19	12	10	6	5	4	3	2	2	2	2	1	1
5.00	24	24	24	20	12	10	6	5	4	3	2	2	2	2	1	1
10.00	48	48	33	20	12	10	6	5	4	3	2	2	2	2	1	1
20.00	50	50	33	20	12	10	6	5	4	3	2	2	2	2	1	1
30.00	50	50	33	20	12	10	6	5	4	3	2	2	2	2	1	1
40.00	50	50	33	20	12	10	6	5	4	3	2	2	2	2	1	1
50.00	50	50	33	20	12	10	6	5	4	3	2	2	2	2	1	1
100.00	50	50	33	20	12	10	6	5	4	3	2	2	2	2	1	1
1000.00	50	50	33	20	12	10	6	5	4	3	2	2	2	2	1	1

Line across table indicates point at which constraints become active

TABLE XI

PREDICTED TENDER LOAD LIST QUANTITY
(QUANTITY UNCONSTRAINED)

	UNIT PRICE IN DOLLARS															
DEMAND	1.00	2.00	3.00	5.00	8.00	10.00	15.00	20.00	25.00	30.00	35.00	40.00	45.00	50.00	100.00	1000.00
0.05	0(+1)	0(+1)	0(+1)	0(+1)	0	0	0	0	0	0	0	0	0	0	0	0
0.10	1	0(+1)	0(+1)	0(+1)	0(+1)	0(+1)	0(+1)	0(+1)	0(+1)	0	0	0	0	0	0	0
0.20	1(+1)	1(+1)	1(+1)	1(+1)	0(+2)	0(+2)	0(+1)	0(+1)	0(+1)	0(+1)	0(+1)	0(+1)	0(+1)	0(+1)	0(+1)	0
0.30	2	2	1(+1)	1(+1)	1(+1)	1(+1)	1(+1)	0(+2)	0(+2)	0(+2)	0(+1)	0(+1)	0(+1)	0(+1)	0(+1)	0
0.40	2	2	2	1(+1)	1(+1)	1(+1)	1(+1)	1(+1)	1(+1)	0(+2)	0(+2)	0(+2)	0(+2)	0(+2)	0(+1)	0
0.50	3	2(+1)	2(+1)	2(+1)	2(+1)	1(+2)	1(+2)	1(+2)	1(+1)	1(+1)	1(+1)	0(+2)	0(+2)	0(+2)	0(+2)	0
0.60	3	3	2(+1)	2(+1)	2(+1)	2(+1)	1(+2)	1(+2)	1(+2)	1(+2)	1(+2)	1(+1)	1(+1)	1(+1)	0(+2)	0
0.70	3	3	3	2(+1)	2(+1)	2(+1)	2(+1)	2(+1)	1(+2)	1(+2)	1(+2)	1(+2)	1(+2)	1(+2)	0(+2)	0(+1)
0.80	3	3	3	3	2(+1)	2(+1)	2(+1)	2(+1)	2(+1)	2(+1)	1(+2)	1(+2)	1(+2)	1(+2)	0(+3)	0(+1)
0.90	4	4	3(+1)	3(+1)	3(+1)	3(+1)	2(+2)	2(+2)	2(+2)	2(+2)	2(+1)	2(+1)	1(+2)	1(+2)	1(+2)	0(+1)
1.00	4	4	4	3(+1)	3(+1)	3(+1)	3(+1)	2(+2)	2(+2)	2(+2)	2(+2)	2(+2)	2(+2)	2(+2)	1(+2)	0(+1)
1.25	6	6	6	6	5(+1)	5(+1)	5(+1)	5(+1)	4(+2)	4(+2)	4(+2)	4(+2)	4(+2)	3(+3)	2(+4)	0(+3)
1.50	8	8	8	7(+1)	7(+1)	6(+2)	6(+2)	6(+2)	5(+3)	5(+3)	5(+3)	5(+3)	4(+4)	4(+3)	3(+4)	0(+4)
1.75	9	9	9	8(+1)	8(+1)	8(+1)	7(+2)	7(+2)	6(+3)	6(+3)	6(+3)	6(+3)	5(+4)	5(+4)	4(+4)	0(+5)
2.00	10	10	10	10	9(+1)	9(+1)	8(+2)	8(+2)	7(+3)	7(+3)	7(+3)	7(+3)	6(+4)	6(+4)	5(+4)	0(+5)
3.00	15	15	15	15	14(+1)	14(+1)	13(+2)	12(+3)	12(+3)	11(+4)	11(+4)	11(+4)	10(+5)	10(+5)	8(+6)	0(+9)
4.00	19	19	19	19	19	19	18(+1)	17(+2)	16(+3)	16(+3)	15(+4)	15(+4)	15(+4)	14(+5)	12(+7)	0(+13)
5.00	24	24	24	24	24	24	23(+1)	22(+2)	21(+3)	21(+3)	20(+4)	20(+4)	19(+5)	19(+5)	16(+8)	0(+17)
10.00	48	48	48	48	48	48	48	48	46(+2)	45(+3)	44(+4)	43(+5)	43(+5)	42(+6)	37(+11)	10(+29)
20.00	95	95	95	95	95	95	95	95	95	95	95	95	94(+1)	92(+3)	83(+12)	42(+46)
30.00	142	142	142	142	142	142	142	142	142	142	142	142	142	142	133(+9)	77(+62)
40.00	189	189	189	189	189	189	189	189	189	189	189	189	189	189	184(+5)	114(+75)
50.00	237	237	237	237	237	237	237	237	237	237	237	237	237	237	237	153(+84)
100.00	473	473	473	473	473	473	473	473	473	473	473	473	473	473	473	364(+109)
1000.00	4723	4723	4723	4723	4723	4723	4723	4723	4723	4723	4723	4723	4723	4723	4723	4723

TABLE XII

PREDICTED TENDER LOAD LIST QUANTITY
(QUANTITY CONSTRAINED)

UNIT PRICE IN DOLLARS

DEMAND	1.00	2.00	3.00	5.00	8.00	10.00	15.00	20.00	25.00	30.00	35.00	40.00	45.00	50.00	100.00	1000.00
0.05	0(+1)	0(+1)	0(+1)	0(+1)	0	0	0	0	0	0	0	0	0	0	0	0
0.10	1	0(+1)	0(+1)	0(+1)	0(+1)	0(+1)	0(+1)	0(+1)	0(+1)	0	0	0	0	0	0	0
0.20	1(+1)	1(+1)	1(+1)	1(+1)	0(+2)	0(+2)	0(+1)	0(+1)	0(+1)	0(+1)	0(+1)	0(+1)	0(+1)	0(+1)	0(+1)	0
0.30	2	2	1(+1)	1(+1)	1(+1)	1(+1)	1(+1)	0(+2)	0(+2)	0(+2)	0(+1)	0(+1)	0(+1)	0(+1)	0(+1)	0
0.40	2	2	2	1(+1)	1(+1)	1(+1)	1(+1)	1(+1)	1(+1)	0(+2)	0(+2)	0(+2)	0(+2)	0(+2)	0(+1)	0
0.50	3	2(+1)	2(+1)	2(+1)	2(+1)	1(+2)	1(+2)	1(+2)	1(+1)	1(+1)	1(+1)	0(+2)	0(+2)	0(+2)	0(+1)	0
0.60	3	3	2(+1)	2(+1)	2(+1)	2(+1)	1(+2)	1(+2)	1(+2)	1(+2)	1(+1)	1(+1)	1(+1)	1(+1)	0(+1)	0
0.70	3	3	3	2(+1)	2(+1)	2(+1)	2(+1)	2(+1)	1(+2)	1(+2)	1(+1)	1(+1)	1(+1)	1(+1)	0(+1)	0(+1)
0.80	3	3	3	3	2(+1)	2(+1)	2(+1)	2(+1)	2(+1)	2(+1)	1(+1)	1(+1)	1(+1)	1(+1)	0(+1)	0(+1)
0.90	4	4	3(+1)	3(+1)	3(+1)	3(+1)	2(+2)	2(+2)	2(+2)	2(+1)	2	2	1(+1)	1(+1)	1	0(+1)
1.00	4	4	4	3(+1)	3(+1)	3(+1)	3(+1)	2(+2)	2(+2)	2(+1)	2	2	2	2	1	0(+1)
1.25	6	6	6	6	5(+1)	5(+1)	5(+1)	5	4	3	2	2	2	2	1	0(+1)
1.50	8	8	8	7(+1)	7(+1)	6(+2)	6	5	4	3	2	2	2	2	1	0(+1)
1.75	9	9	9	8(+1)	8(+1)	8(+1)	6	5	4	3	2	2	2	2	1	0(+1)
2.00	10	10	10	10	9(+1)	9(+1)	6	5	4	3	2	2	2	2	1	0(+1)
3.00	15	15	15	15	12	10	6	5	4	3	2	2	2	2	1	0(+1)
4.00	19	19	19	19	12	10	6	5	4	3	2	2	2	2	1	0(+1)
5.00	24	24	24	20	12	10	6	5	4	3	2	2	2	2	1	0(+1)
10.00	48	48	33	20	12	10	6	5	4	3	2	2	2	2	1	1
20.00	50	50	33	20	12	10	6	5	4	3	2	2	2	2	1	1
30.00	50	50	33	20	12	10	6	5	4	3	2	2	2	2	1	1
40.00	50	50	33	20	12	10	6	5	4	3	2	2	2	2	1	1
50.00	50	50	33	20	12	10	6	5	4	3	2	2	2	2	1	1
100.00	50	50	33	20	12	10	6	5	4	3	2	2	2	2	1	1
1000.00	50	50	33	20	12	10	6	5	4	3	2	2	2	2	1	1

Line across table indicates point at which constraints become active

TABLE XIII

PREDICTED TENDER LOAD LIST QUANTITY
$\lambda = 0.00035$
HISTORICAL DEMAND

UNIT PRICE

QTRLY DEMAND	< $1	$1-$5	$5-$10	$10-$25	$25-$50	$50-$100	$100-$250	$250-$500	$500-$1000	$1000-$2500	$2500-$5000	$5000-$10000
0.01	0	0	0	0	0	0	0	0	0	0	0	0
0.02	1	0	0	0	0	0	0	0	0	0	0	0
0.03	1	0	0	0	0	0	0	0	0	0	0	0
0.04	1	1	0	0	0	0	0	0	0	0	0	0
0.05	1	1	0	0	0	0	0	0	0	0	0	0
0.06	1	1	1	0	0	0	0	0	0	0	0	0
0.07	1	1	1	0	0	0	0	0	0	0	0	0
0.08	1	1	1	1	0	0	0	0	0	0	0	0
0.09	1	1	1	1	0	0	0	0	0	0	0	0
0.10	1	1	1	1	0	0	0	0	0	0	0	0
0.20	2	2	2	1	1	1	0	0	0	0	0	0
0.30	2	2	2	2	1	1	1	0	0	0	0	0
0.40	2	2	2	2	2	1	1	1	0	0	0	0
0.50	3	3	3	3	2	2	1	1	0	0	0	0
0.60	3	3	3	3	3	2	2	1	1	0	0	0
0.70	3	3	3	3	3	2	2	1	1	0	0	0
0.80	3	3	3	3	3	3	2	2	1	0	0	0
0.90	4	4	4	4	3	3	2	2	1	0	0	0
1.00	4	4	4	4	4	3	3	2	2	1	0	0
1.25	6	6	6	6	6	6	5	4	3	2	0	0
1.50	8	8	8	8	8	7	6	5	4	3	0	0
1.75	9	9	9	9	9	8	7	6	5	3	0	0
2.00	10	10	10	10	10	10	8	7	6	4	1	0
3.00	15	15	15	15	15	15	13	12	10	7	4	0
4.00	19	19	19	19	19	19	18	16	14	11	7	2

TABLE XIII (CONT'D)

	< $1	$1-$5	$5-$10	$10-$25	$25-$50	$50-$100	$100-$250	$250-$500	$500-$1000	$1000-$2500	$2500-$5000	$5000-$10000
5.00	24	24	24	24	24	24	23	21	18	15	11	5
6.00	29	29	29	29	29	29	29	26	23	19	14	8
7.00	34	34	34	34	34	34	34	31	27	23	17	11
8.00	38	38	38	38	38	38	38	36	32	27	21	14
9.00	43	43	43	43	43	43	43	41	37	31	25	17
10.00	48	48	48	48	48	48	48	46	42	35	28	21
20.00	95	95	95	95	95	95	95	95	92	80	69	56
30.00	142	142	142	142	142	142	142	142	142	129	113	96
40.00	189	189	189	189	189	189	189	189	189	179	158	137
50.00	237	237	237	237	237	237	237	237	237	230	206	180
100.00	473	473	473	473	473	473	473	473	473	473	456	411

TABLE XIV

PREDICTED TENDER LOAD LIST QUANTITY

$\lambda = 0.00035$

NO HISTORICAL DEMAND

UNIT PRICE

QTRLY DEMAND	< $1	$1-$5	$5-$10	$10-$25	$25-$50	$50-$100	$100-$250	$250-$500	$500-$1000	$1000-$2500	$2500-$5000	$5000-$10000
0.01	0	0	0	0	0	0	0	0	0	0	0	0
0.02	1	0	0	0	0	0	0	0	0	0	0	0
0.03	1	0	0	0	0	0	0	0	0	0	0	0
0.04	1	1	0	0	0	0	0	0	0	0	0	0
0.05	1	1	0	0	0	0	0	0	0	0	0	0
0.06	1	1	1	0	0	0	0	0	0	0	0	0
0.07	1	1	1	0	0	0	0	0	0	0	0	0
0.08	1	1	1	1	0	0	0	0	0	0	0	0
0.09	1	1	1	1	0	0	0	0	0	0	0	0
0.10	1	1	1	1	0	0	0	0	0	0	0	0
0.20	2	2	2	1	1	1	0	0	0	0	0	0
0.30	2	2	2	2	1	1	1	0	0	0	0	0
0.40	2	2	2	2	2	1	1	1	0	0	0	0
0.50	3	3	3	3	2	1	1	1	0	0	0	0
0.60	3	3	3	3	2	1	1	1	1	0	0	0
0.70	3	3	3	3	2	1	1	1	1	0	0	0
0.80	3	3	3	3	2	1	1	1	1	0	0	0
0.90	4	4	4	4	2	1	1	1	1	0	0	0
1.00	4	4	4	4	2	1	1	1	1	1	0	0
1.25	6	6	6	5	2	1	1	1	1	1	0	0
1.50	8	8	8	5	2	1	1	1	1	1	0	0
1.75	9	9	9	5	2	1	1	1	1	1	0	0
2.00	10	10	10	5	2	1	1	1	1	1	1	0
3.00	15	15	13	5	2	1	1	1	1	1	1	0
4.00	19	19	13	5	2	1	1	1	1	1	1	1

TECHNICAL REPORT NUMBER 01862.01-1

STOCK LIST PROVISIONING PROCEDURE

WITH

DETAILED AN/SPS-40 RADAR APPLICATION

FINAL REPORT

Prepared For
ELECTRONICS MAINTENANCE ENGINEERING CENTER
NORFOLK, VIRGINIA

A. E. Rupp

Contracts N189(181)58090A and N189(62678)60125A

Approved:

W. L. Freienmuth

W. L. Freienmuth, Manager
Research and Development Branch

SEPTEMBER 1966

VITRO LABORATORIES
SILVER SPRING, MARYLAND 20910

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ABSTRACT

During the performance of equipment evaluation by the Electronics Maintenance Engineering Center, it was found that a major source of difficulties resulted from inadequate logistic support. This logistic problem was found to be acute on the AN/SPS-40 Radar System. Because of this situation Vitro undertook a logistics study for the Navy under the direction of the Electronics Maintenance Engineering Center.

This report presents the results of the logistics study to determine the procedures required to establish a spare parts provisioning list and to develop a computer program for performing the necessary associated calculations. The methods applied are probabilistic in nature involving the determination of the support necessary to meet a provisioning level. The provisioning level is defined as the likelihood that an equipment or system will be able to operate for a given period of time without experiencing a stock out or shortage of spare parts. The criterion followed in determining the sequence in which parts are considered for sparing is to progressively select the part which indicates the highest likelihood of requiring replacement. When sufficient parts have been added to accumulate the desired level, the calculation is complete.

This procedure has been developed for a three echelon supply system composed of equipment site, intermediate stocking point, and major supply depot. In order to properly generate a stock list for each of the above three locations the following five items of information are used:

1. Complete equipment composition - identification of every part in the system by part type.
2. Maintenance policy - lowest location at which replacement or repair can be effected.
3. Item consumption rate - the rate applied is dependent upon the maintenance policy stipulated and therefore may be a replacement ~~requirement~~ rate, failure rate, or mortality rate.
4. Usage factor - measure of expected usage of the equipment or system during the stock period.
5. Stock policy - additional constraints applied which may require special consideration, e.g., critical part applications. A code format was developed whereby the computer considers the above information during compilation of the stock list.

In order to test the ability of the generated procedures, stock lists were produced for the AN/SPS-40 Radar which is composed of 11,729 part applications. The provisioning parameters used were:

Equipment	- 90% provisioning level for a 3 month stock period.
Support Ship	- 95% provisioning level for a 6 month stock period and 6 equipments per support ship.
Depot	- 99% provisioning level for a 6 month stock period and 42 equipments per depot.

The above provisioning parameters were used to generate three sets of stock lists corresponding to three maintenance policies which were: (1) all maintenance performed by the technician aboard ship except for the antenna assembly; (2) 84 assemblies maintained by the contractor, 3 units maintained by the Yard, and the remainder of the equipment maintained by the technician

aboard ship; and (3) 107 units and assemblies maintained by a Navy module Repair Facility and the remaining 62 units and assemblies maintained by the technician aboard ship. A summary of the results of the stock lists produced for each of the three maintenance policies is shown below.

	Prov. Level	Range	Depth	Cost
Technician Repair	90.0%	1,809	2,103	$ 78,000.00
Partial Contractor Repair	94.1%	1,442	1,698	$131,000.00
Partial Facility Repair	94.9%	1,480	2,095	$ 90,000.00

The provisioning level in two cases above was greater than 90% because at least one of every critical shipboard installable item was added to the stock list. For comparison purposes the June 1965 Allowance Parts Lists and an Electronic Maintenance Engineering Center stock list produced the following results:

	Prov. Level	Range	Depth	Cost
June 1965 APL	1.0%	1,224	2,032	$70,000.00
EMEC Stock List	8.4%	987	1,548	$67,000.00

The results also indicated that if $67,000.00, the cost of the EMEC stock list, were used as a constraint, the maximum provisioning level obtainable for that cost by the computerized program for the Partial Facility Repair case would be 38%.

Cost analysis of the three maintenance policies are compared below.

Stock Cost Per Equipment

	Technician Repair *	Partial Contractor Repair	Partial Facility Repair
Ship	$78,000.00	$131,000.00	$ 90,000.00
Support Ship	12,000.00	20,000.00	20,000.00
Depot	8,000.00	14,000.00	12,000.00
Total	$99,000.00	$165,000.00	$122,000.00

The obvious conclusion is that logistics costs are held to a minimum when the technician aboard ship performs all the repairs. This is not to say that technician repair is the most economical for the Navy, since training, test equipment and facility costs have not been considered.

The above cost results illustrate the effect of maintenance policy on the stock lists produced and the sensitivity of the procedure to maintenance policy. The procedure has also been found to be sensitive to the control factors of part consumption rates and part population. There is flexibility of handling combinations of parts, assemblies, and units as well as incorporating special stocking policies such as limiting equipment site or ship inventory by assigning low usage-high cost items to the support ship.

While this procedure has application to generating stock lists which will account for the maintenance capability of each ship, the type of duty being performed, or based on budget constraints; the recommended application is in the area of initial provisioning where stock lists would be produced prior to the provisioning conference. Appraisal of the generated stock list by the contractor, supply personnel, and project manager would establish the basis for the provisioning conference decisions.

* Rounded off values

FOREWORD

This report contains a description of the work accomplished under two separate contracts for logistics analysis of the AN/SPS-40 Radar for the Electronics Maintenance Engineering Center. The effort on the first contract is referred to as Phase I and specifically covers Contract N189 (181)58090A for the period beginning 15 May 1964 and ending 29 March 1965. The effort on the second contract is referred to as Phase II and specifically covers Contract N189(62678)60125A for the period beginning 29 December 1965 and ending 30 April 1966. The efforts performed on Phase I and Phase II vary in detail but are closely related in approach and procedure.

Phase I concentrates on the development of the provisioning procedures. Also included in Phase I is the application of the provisioning procedure based on four different maintenance policies which produced stock quantities for the equipment, support ship, and depot. The four types of stock lists were produced to evaluate the ability, utility, and sensitivity of the provisioning procedure. Phase II presents the effort involved in generating parts lists and stock lists for a specific and detailed maintenance policy which was formulated by the Electronics Maintenance Engineering Center after a thorough investigation of the AN/SPS-40 Radar's configuration and requirements.

Section I
INTRODUCTION

This is the final report of work on Contract N189(181)58090A covering the period beginning 15 May 1964 and ending 29 March 1965, and Contract N189(62678)60125A covering the period beginning 29 December 1965 and ending 30 April 1966. Under these contracts Vitro Laboratories has performed a logistic analysis of the AN/SPS-40 Radar System incorporating all field changes up to and including Field Change No. 12, determined the procedures required to establish the spare parts provisioning list, developed a computer program for performing the necessary calculations, and produced spare part provisioning lists for ship (one AN/SPS-40), support ship, and depot. In addition, the provisioning lists for shipboard developed in this program were compared with lists developed by the Navy during 1963, 1964 and 1965 for protection level as well as cost, weight and volume.

The methods applied are probabilistic in nature involving the determination of the support necessary to meet a provisioning level. The provisioning level is defined as the probability that an equipment or system will not require more than a stated number of spare parts during a specified period of time. This definition may be restated as the likelihood that an equipment or system will be able to operate for a given period of time without experiencing a stock out or shortage of spare parts. In order to calculate the provisioning level, it is first necessary to determine all

parts which are contained within the system and the associated replacement rate for each part. Using the Poisson probability distribution function for replacement times and the desired provisioning level, the number of spares is computed using the part type populations and replacement rates. The criterion followed in determining the sequence in which parts are considered for sparing is to progressively select the part which indicates the highest likelihood of requiring replacement. When sufficient parts have been added to accumulate the desired provisioning level, the calculation is complete.

A standby concept is inherent in the procedures applied in this study. Mathematically the standby concept means that a spare part is considered to be the same as a redundant nonoperating part in the equipment which is always ready to be instantly "switched" into service upon requirement. A computer program has been developed to perform the necessary calculations which for this program is estimated to be in the neighborhood of 20,000,000 mathematical operations requiring approximately one hour run time on the 7090 computer.

Sections II through VII discuss the effort performed under Phase I, Contract N189(181)58090A. Sections VIII through XI present the work accomplished under Phase II, Contract N189(62678)60125A.

Section II
SUMMARY OF WORK

The program outputs developed during Phase I are shown diagrammatically in figure 1, which also roughly shows the method for producing the outputs. The references to other figure numbers are a handy cross reference to detailed results.

EQUIPMENT STOCK LISTS

Results include the generation of four separate equipment stock lists for the AN/SPS-40 radar which include only shipboard installable items. The four stock lists are based on (1) critical and noncritical parts, (2) critical parts only, (3) provisioning all critical parts in unity depth or greater, and (4) critical/noncritical parts and assemblies. A critical item is defined as one which is essential to the operation of the unit in which it is located. Conversely, noncritical items are those which are not essential to the operation of the radar. The two stock lists based on (1) critical and noncritical parts, and (2) critical and noncritical parts and assemblies are accompanied by a description of the influence of the stock period variations and associated constraints of weight, cost, and cube. In most cases, for ships and shore stations, a chosen fixed quantity of spares located in a stock room must provide for all replacements within an equipment during normal operating periods. At certain intervals the spare part quantities depleted from the stock room are replenished through the

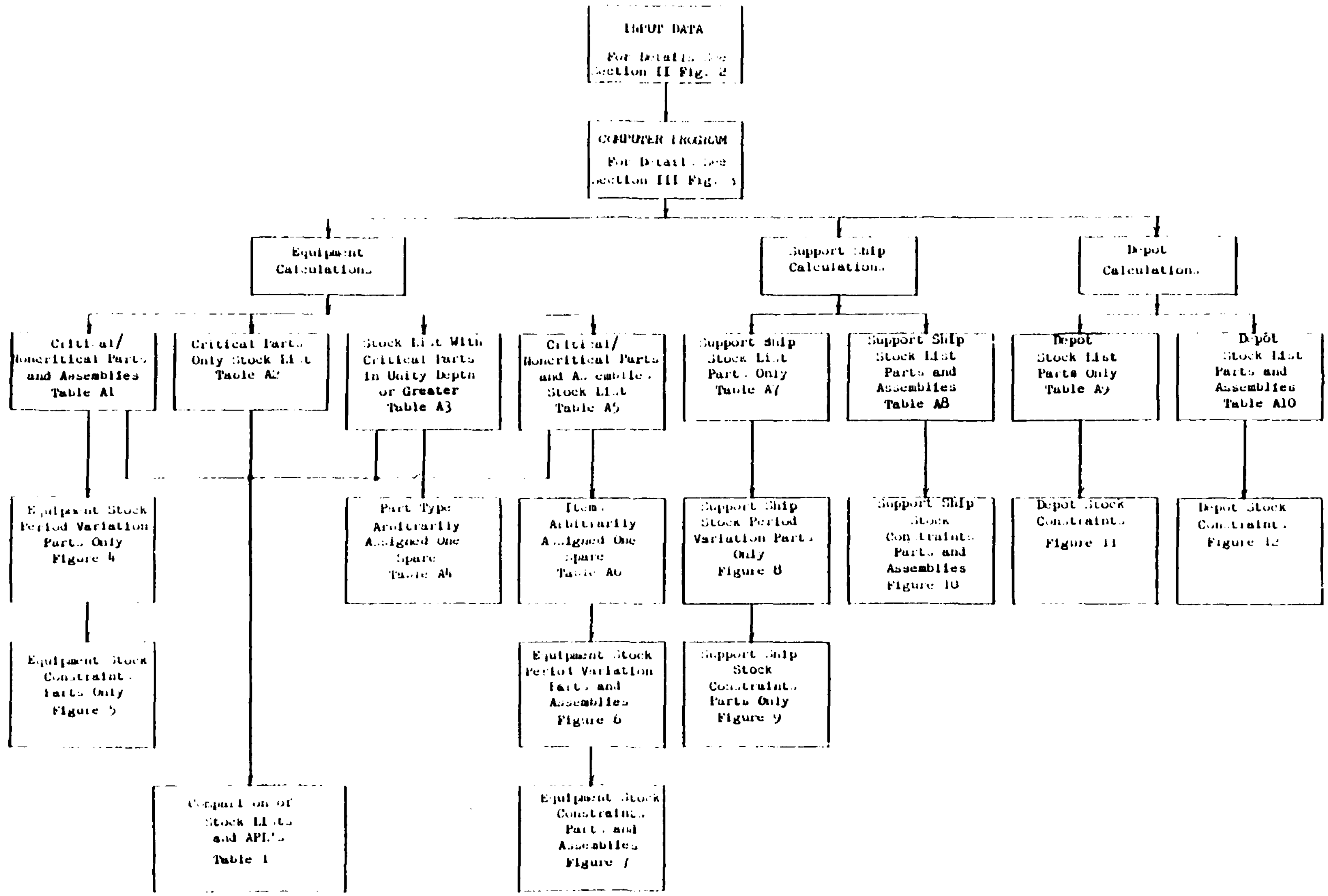


Figure 1. Program Summary - Phase I

Navy logistics system. The calendar time interval between replenishments of the equipment stock room is known as the stock period. During the stock period the equipment may draw replacements from its stock room but not from any outside source. The provisioning results obtained for the four equipment stock lists described above are compared with the provisioning recommendations in two generations of the Navy's Allowance Parts Lists for the AN/SPS-40 Radar and an EMEC adjustment of the parts and assemblies stock list.

The spare parts provisioning list for critical and noncritical parts contains only those parts installable by ship's force. This list recommends the part types and quantities to be stocked on board a ship for one AN/SPS-40 Radar. The complete provisioning list is set forth in table A-1 (all "A" tables are in separate appendix) which contains a range of 1,509 part types and a depth of 2,103 parts. This list assumes that all repairs made on the radar will be performed by the assigned Navy technician. The stock list was calculated on the basis of a 90% provisioning level, or that nine times out of ten the radar would have sufficient spares to make required replacements during 90 days of operation without replenishment. The above provisioning list supplies not only normal usage for the 90 day period, but also includes sufficient back-up spares to insure that only one time out of ten on the average will the system experience a stock out during a 90-day period due to the lack of parts which are installable by the ship's force.

Normal usage consists of the expected number of parts which will be consumed by the equipment during a given time period. Normal usage is

sometimes referred to as demand based items. All spare parts stocked in excess of normal usage by the equipment during the stated time period are known as back-up spares or insurance items.

The provisioning list discussed above was determined for the 90% level for the equipment which included both the critical and noncritical parts. The provisioning list of table A-2 considers only the critical parts which have been provisioned to the 90% level. This list contains a range of 1,502 part types and a depth of 1,741 parts.

The provisioning list of table A-3 contains at least one spare part for every critical shipboard installable part type. This list was developed initially by computing a 90% provisioning level for all shipboard installable parts, critical and noncritical. Then, all critical part types which did not have a spare provided by the above calculation were arbitrarily assigned one spare part. This means that all critical shipboard installable items are stocked in the provisioning list of table A-3 in unity depth or greater. The provisioning level for this spare complement, which has a range of 2,043 different part types and a depth of 2,337 parts, was calculated and found to be 93.9%.

Table A-4 sets forth those critical parts arbitrarily assigned one spare in the development of the provisioning list of table A-3.

The provisioning list of table A-5 was determined for a maintenance policy stipulating that Navy technicians would not make all of the repairs on the AN/SPS-40 but that 84 assembly types would be returned to the manufacturer for repair and three units would be repaired by the shipyard. The manufacturer repairable assembly list was furnished for this program

by the EMEC. As in the case of the preceding stock list, a 90% provisioning level was initially determined for the critical and noncritical items (parts and assemblies) and then all critical shipboard installable items were stocked in unity depth or greater. The provisioning level for this spare complement which has a range of 1,442 different items (part types plus assembly types) and a total depth of 1,698 items was calculated and found to be 94.1%.

The stock list of table A-5 was adjusted by EMEC in accordance with their experience on the AN/SPS-40 Radar. The resultant stock list had a range of 1,458 item types, a depth of 1,706 items, and a computed provisioning level of 92.9%. This list is not provided with the report.

Provisioning levels were determined for the AN/SPS-40 Radar Allowance Parts List dated February 1963 and the AN/SPS-40 Radar Allowance Parts List dated November 1964. Replacement rates were assigned to the part quantities shown in the stock number sequence list, Section C, of the APL's and the provisioning levels were calculated to be 0.5% for the APL dated February 1963 and 1.0% for the APL dated November 1964. The older APL includes Field Changes 1 through 9 and the later APL includes Field Changes 1 through 12. The APL's provide spares for both critical and noncritical items.

A comparison of the provisioning lists compiled during Phase I of the program and the stock lists as presented in the two APL's is shown in table 1.

Throughout the Phase I effort, the AN/SPS-40 parts list was reviewed and updated to most accurately reflect the current equipment parts complement. In this process changes were made to the APL involving about

TABLE 1. EQUIPMENT RESULTS SUMMARY-PHASE I

Stock List Identification	Calculated Provisioning Level (Percent)	Range - No. of Different Part Types	Depth - Total No. of Parts	Cost (Dollars)	Weight (Pounds)	Cube (Cu. Ft.)
Critical/Noncritical Parts	90.0	1,809	2,103	78,058	1,472	174
Critical Parts Only	90.0	1,502	1,741	75,087	1,400	172
Critical Parts (Min. Depth)	93.9	2,043	2,337	79,190	1,494	190
Critical/Noncritical Parts & Assemblies	94.1	1,442	1,698	131,326	1,331	155
EMEC Adjusted Parts & Assemblies	92.9	1,458	1,706	100,212	711	121
Old APL (Dated Feb. '63)	0.5	1,161	2,132	93,867	928	119
New APL (Dated Nov. '64)	1.0	1,297	2,455	93,620	1,006	86

17% of total circuit symbols. There were 2% of the APL circuit symbols which were found not to be in the equipment. The remaining changes consisted of identifying parts by a manufacturer's number or changing Federal Stock Numbers. The net result being that over 1,600 changes were made to the APL.

SUPPORT SHIP STOCK LIST

The second group of results is concerned with support ship provisioning for the AN/SPS-40 and includes two support ship stock lists, a description of the influence of stock period variations, and constraints of weight, cost, and cube.

The first provisioning list considers critical and noncritical parts for the support ship, table A-7, computed for 95% provisioning level for a support ship servicing six equipments or systems for a six-month period of time. For the procedure used in this analysis, the support ship is not expected to load normal usage items but carries only the necessary back-up items to insure that if the six equipments with their respective provisioning list of table A-1 are in the company of a support ship with a provisioning list of table A-7, then only five times out of a hundred will any of the six radar systems supplied by the support ship experience a stock-out of a shipboard installable part. Since the support ship is carrying back-up items only, it is required to stock 2,133 part types and a total of 2,264 items.

The provisioning list of table A-7 assumes that all repairs will be made by Navy technicians. The support ship provisioning list of table A-8 was generated under the condition that the 34 EMEC specified assemblies

and 3 units were not repairable by the ship's force. Table A-8 shows that the support ship is required to stock a range of 581 different type items and a total depth of 902 items. With the exception of the distribution between parts and assemblies all other conditions were the same for generating tables A-7 and A-8.

DEPOT STOCK LIST

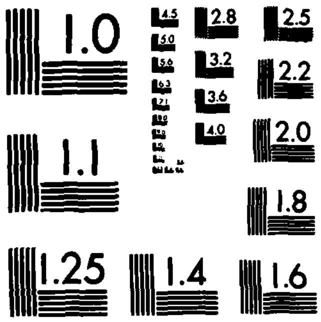
The third set of results is the two depot stock lists for the AN/SPS-40 Radar and the associated constraints of weight, cost, and cube.

Table A-9 shows the recommended stock to be carried by a depot which supplies 42 equipments with parts when all repairs are made by Navy technicians. Table A-10 shows depot stock quantities for support of 42 equipments when the EMEC specified assemblies are manufacturer repaired and three units are shipyard repaired. The expected or normal usage based on three months has been indicated which are the items expected to have a high velocity or rapid movement. The back-up items required to reach the 99% provisioning level are based on a six-month period. The depot carries not only the ship installable items, but also the yard installable items.

In Section V the figures 4 and 6 for equipment and figure 8 for the support ship show the variation in provisioning level as a function of the stock period. Using these graphs it is possible to determine the probability of having sufficient quantity of spare parts for any anticipated stock period. If weight, cost, or cube become constraining factors, the graphs shown in figures 5, 7, 9, 10, 11, and 12 in Section V may be used to determine the provisioning level dictated by such constraints.

AD-A099 777 SURVEY AND ASSESSMENT OF MODELS OR DECISION RULES DETERMINING SPARE PARTS..(U) AUTOMATION INDUSTRIES INC SILVER SPRING MD VITRO LABS DIV R I POWELL ET AL. 4/10

UNCLASSIFIED 07 SEP 79 TR-03133.100-1-APP-A F/G 15/5 NL


1.0
4.5
5.0
5.6
2.8
2.5
3.2
2.2
3.6
4.0
2.0
1.1
1.8
1.25
1.4
1.6

Section III
INPUT DATA

The acquisition of suitable input data for the AN/SPS-40 logistic program involved collecting, validating, and assembling into a concise usable format, information from a variety of sources and in many different formats. Figure 2 depicts the path of each different item of information, through various check and conversion procedures, to the final format selected for use as program input.

The remaining paragraphs of this section provide a description of each data source and of the various steps employed in transforming the data from its original state to the final program input format.

DATA SOURCES

The various data sources employed to derive the input information for the program are listed below, together with a brief description of the type and quality of the information obtained from each source.

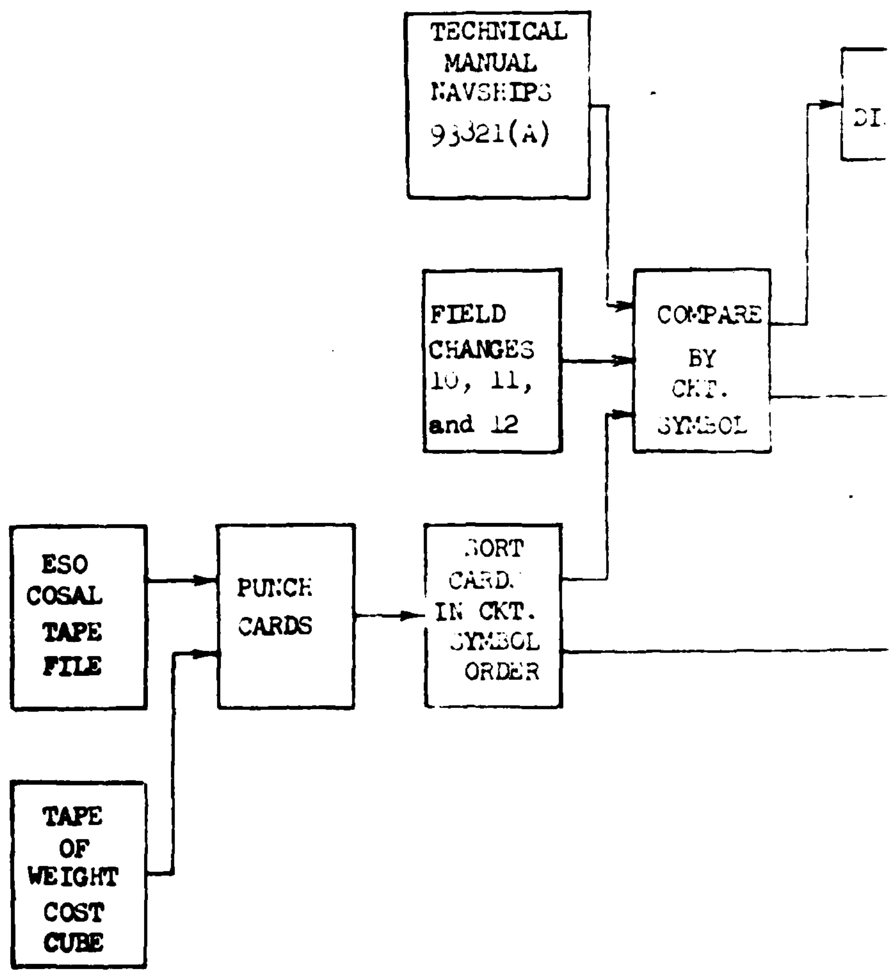
1. ESO DATA. The ESO Section B, COSAL (Coordinated Ships Allowance List) file was used as the primary data source for determining the parts complement of the AN/SPS-40 and the weight, cube, and cost of these parts. This data file was on hand at Vitro in the form of magnetic tape as a result of logistic studies done for the Bureau of Supplies and Accounts. This file did not reflect the changes to the parts complement brought about by Field Changes 10, 11, and 12 and it failed to provide Federal Stock

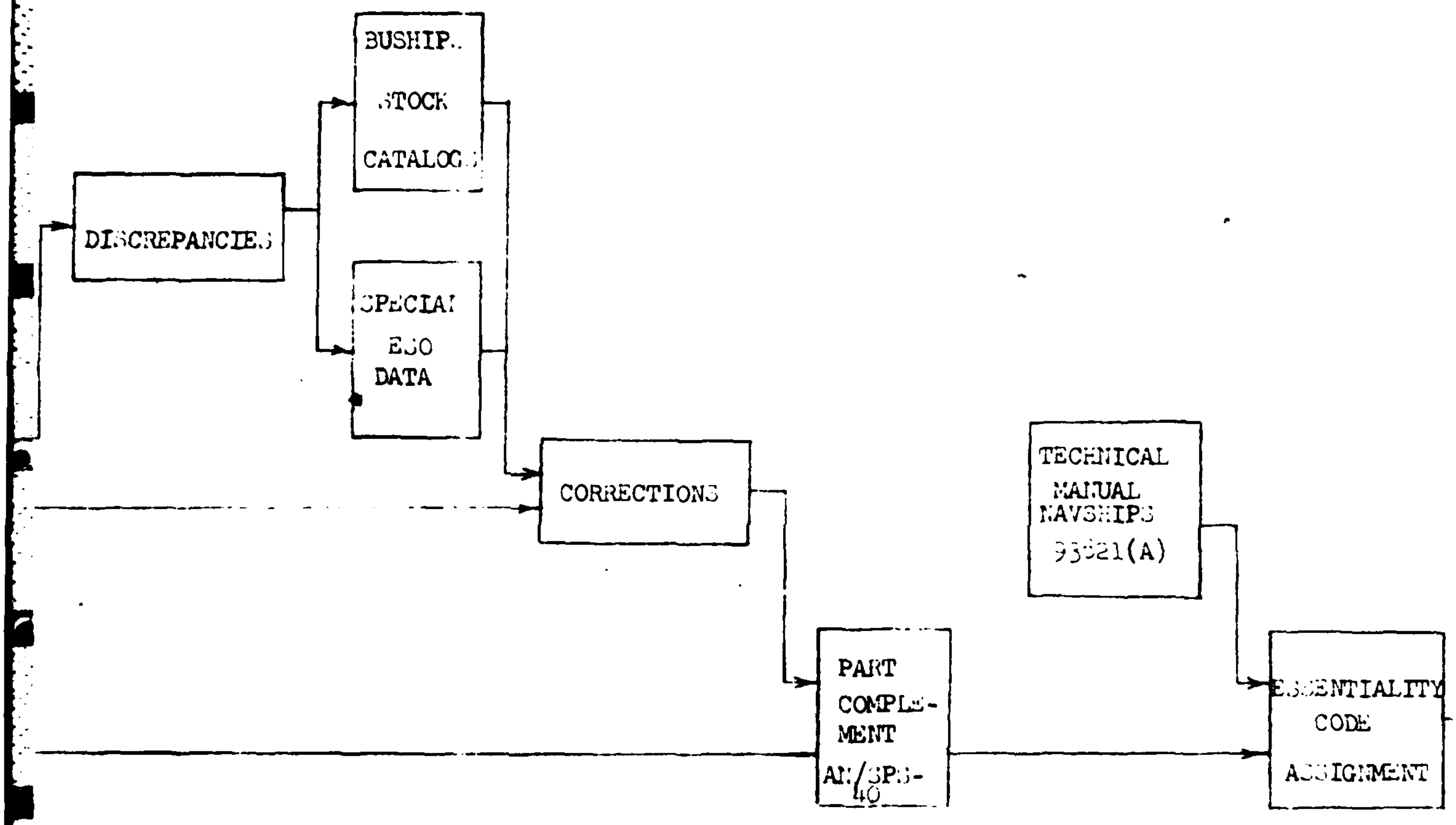
Numbers for approximately ten percent of the total part types. The Allowance Parts List of February 1963 and November 1964 were also used for determining the parts complement. The COSAL tape and the APL's together identified 9,787 circuit symbols.

2. The equipment technical manual, NAVSHIPS 93821(A), together with changes 1, 2 and 3 identified the configuration of the AN/SPS-40 with all Field Changes through 12 completed, and was therefore assumed to be the most accurate source of part information available. The parts list section of 93821(A) was used to update and correct the parts complement derived from the ESO DATA (Item 1). The schematics, pictorial part location diagrams, repair instructions, and general description section of 93821(A) provided the background required for assigning an essentiality code (EC) to each part. NAVSHIPS 93821(A) was not very useful as a source of FSN identification, most parts being identified by Lockheed Drawing Number or other manufacturer's designation.

The manual was used as the source for identifying 339 manufacturer's numbers. An additional 364 circuit symbols were found to be contained within the equipments that were not listed in the ESO data. There were 128 circuit symbols specified by the ESO data which according to the manuals are not in the equipment. The manual contributed a total of 908 changes to the ESO data file. The manuals are considered to be the most reliable source of part data and problem areas were resolved so that the stock list part complement agreed with the manuals.

3. Vitro Technical Note 1744.00-2 - This report was used as the primary source of replacement rate information. This report contains;


TECHNICAL MANUAL NAVSHIPS 93321(A)
FIELD CHANGES 10, 11, and 12
COMPARE BY CKT. SYMBOL
ESO COSAL TAPE FILE
PUNCH CARDS
SORT CARDS IN CKT. SYMBOL ORDER
TAPE OF WEIGHT COST CUBE


BUSHIPS STOCK CATALOGS
DISCREPANCIES
SPECIAL ESO DATA
CORRECTIONS
TECHNICAL MANUAL NAVSHIPS 93821(A)
PART COMPLEMENT AN/SPS-40
ESSENTIALITY CODE ASSIGNMENT

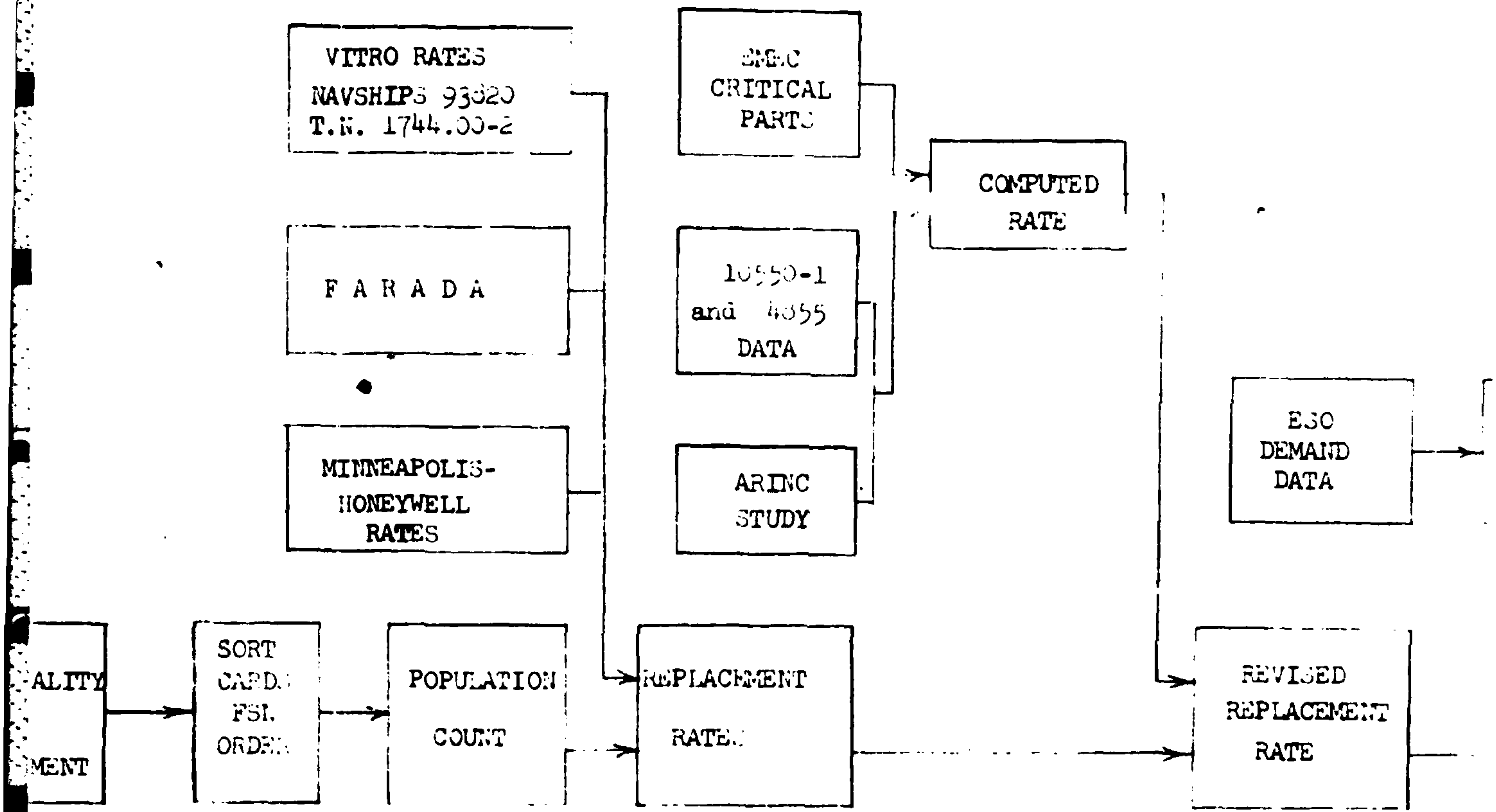
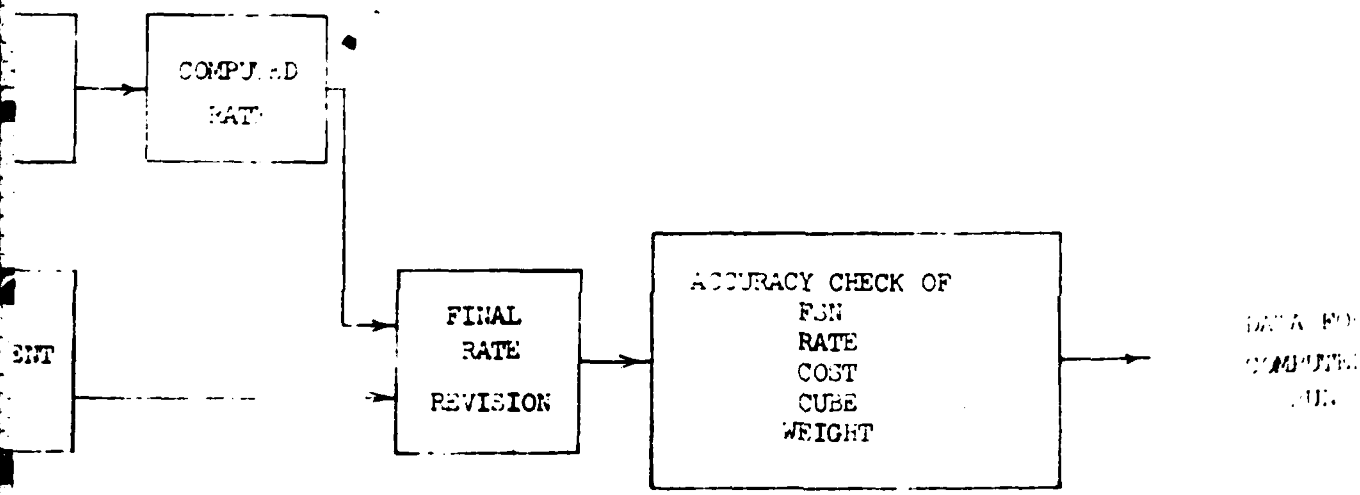


Figure 2. Input Data Flow Diagram


FINAL
RATE
REVISION
ACCURACY CHECK OF
FSN
RATE
COST
CUBE
WEIGHT

4

(a) replacement rates for electron tubes by individual tube type, (b) replacement rates for electronic parts by generic part type, and (c) ratio of replacements to primary failures for electronic parts by generic part type. The replacement rates found in this report were based upon replacements reported by the DD787 Electronic Failure Report collected over a sixteen month period from April 1959 through July 1960. There were 37,619 equipments representing 112 different equipment types with a total of 273,275 replacements during a total combined operating time of 179,773,900 hours that were analyzed to determine the replacement rates.

4. NAVSHIPS 93820 (Vitro TR-133) Handbook for the Prediction of Shipboard and Shore Electronic Equipment Reliability. This report was used as the primary source of part failure rates for electronic parts. Rates are given for generic part type and by various sub-classifications within many of the part types. The rates published in NAVSHIPS 93820 were based on reporting from 47,812 equipments representing 183 equipment types with an accumulation of 320,481,383 hours of operating time. NAVSHIPS 93820 was originally published in April 1961 and has been revised twice, November 1962 and April 1964.

5. FARADA. The Failure Rate Data Collection Program (FARADA) sponsored by the Bureau of Naval Weapons has collected and published a book of part failure rates derived from a multitude of sources and covering many classes of parts. This failure rate book was used as a secondary source of electronic part failure rates and as the primary source of failure rates for all non-electronic items. FARADA is considered to be a less desirable source of failure rates than NAVSHIPS 93820 since most of the rates published in FARADA are based upon fewer failures and operating hours than

those of NAVSHIPS 93820. Additionally, the FARADA rates are based upon a wide range of applications with only a few items coming from the Naval shipboard environment.

6. Minneapolis-Honeywell Aero Florida Failure Rate Handbook. This document is a compilation of parts failure rates from 44 industry and government sources. The quality or applicability of these rates cannot be determined since no background information is presented. This source of rates was used only for those items which were not found in any of the previously listed sources.

7. List of Critical Parts and Assemblies. This list, supplied by EMEC, provides an indication of those parts which fleet experience has indicated as trouble spots, and was used to identify parts requiring special consideration during replacement rate assignments.

8. BUSHIPS 10550-1 and NAVSHIPS 4855. These forms are, respectively, records of parts replacements and equipment operating times. Tabulation of these reports covering the AN/SPS-40 were obtained and the data used to compute some replacement rates. Only a limited number of reports were available on the AN/SPS-40 radar however, resulting in a low confidence in the computed rates.

9. ARINC Report No. 301-01-1-48, Reliability Improvement Program for the AN/SPS-40 Radar Set. This report contains a record of part replacements and equipment operating times determined during a study of the AN/SPS-40. These data were used in the calculation of part replacement rates.

As with source (8), only a low degree of confidence can be placed in the rates derived from the ARINC data because replacements and operating times were derived from the 10550/4855 forms which have indicated a poor completeness of reporting, and the majority of parts considered have only one or zero reported replacements which cannot yield a significant estimate of replacement rate at the parts level.

10. ESO Demand Data Cards. These cards list both the recurrent and non-recurrent demands for items peculiar to the AN/SPS-40 during the current quarter and the preceding six quarters. The recurrent demand figures were used in the calculation of demand rates for comparison with the replacement rates previously derived from other sources. Out of 767 parts peculiar, ESO was unable to provide reporting on 16 items, 10 of these were not ESO cog items and the remaining six were not found in ESO files. It was noted from these demand data, that entire assemblies are being ordered in quantities as recurrent demands where the assemblies are themselves repairable items. The use of demand data for determining a quantitative part consumption rate has the disadvantage of not indicating the end use of the items, the item population, or the item operating time. This means that except in special cases where the additional pertinent information is available the demand data can be used only as qualitative estimates of consumption.

PROCESSING PROCEDURES

The following paragraphs describe in detail the sequence of operations performed to convert the data obtained from the ten sources listed above into the desired input to the AN/SPS-40 logistic program.

1. Program Input Determination. The initial step consisted of listing all of the input information required for the operation of the computer program and arranging these items into an acceptable format. The items to be included for each part type were determined to be: FSN or other identification code (FSN preferred), noun name, cube, weight, cost, population (i.e., total number of a particular part type in an AN/SPS-40), replacement rate, essentiality code, and current SNSL allowed quantity.

2. Part Complement Verification. The steps taken to establish an accurate part complement list for the AN/SPS-40 were (a) convert ESO/COSAL tape to punched cards, (b) sort cards into circuit symbol order, (c) compare COSAL cards to the parts list in NAVSHIPS 93821(A) on circuit symbol basis using 93821(A) as the master list, and (d) prepare new cards to provide the corrections and additions necessary. The correctitons and additions made comprise approximately 10% of the final parts complement list. A total of 10,151 circuit symbols were recorded for use in this analysis.

3. EC Assignment. An essentiality code (EC) was assigned to each part on a circuit symbol basis. The coding used was as follows:

a. Critical and installable by ships force.

b. Critical and not installable by ships force.

c. Noncritical and installable by ships force.

d. Noncritical and not installable by ships force.

The procedure for EC assignment consisted of determining the functional and physical location of each part using the schematic, part location diagrams, repair instructions, etc., of NAVSHIPS 93821(A) and assigning the EC consistent with the determined locations.

4. Determination of Part Type Population. In this step the corrected COSAL card deck was resorted into FSN (or other identity number) order and

a count made for each FSN. A total of 2,178 different types of parts was processed on the AN/SPS-40.

5. Replacement Rate Assignment. A replacement rate was assigned to each part type (FSN) from one of the sources previously listed. A priority list for rate sources was established and the rate for each FSN was taken from the highest ranking source in which an appropriate rate was available. Priority assignments for rate sources were based upon quantity, quality, and appropriateness of material used to prepare the rates. Material quantity involves the collection and use of sufficient replacements and operating hours to insure confidence in the resultant rates. Material quality involves the completeness and accuracy of reporting of the data that were used in rate calculation. Appropriateness involves the environment from which the replacement and operating times were collected; i.e., rates based upon data collected from naval shipboard equipment are more appropriate for use in the program than rates based upon data collected from airborne equipment. The replacement rate source priority list employed is as follows:

a. Vitro Technical Note 1744.00-2 specific part type replacement rates.

b. Failure rate modified by appropriate factor from Technical Note 1744.00-2.

c. Vitro Technical Note 1744.00-2 generic part type replacement rate.

d. Failure rate modified by engineering judgment.

A second priority list for failure rate sources was also established as:

a. NAVSHIPS 93820

b. FARADA

c. Minneapolis-Honeywell Handbook

Following the initial assignment of replacement rates, a second rate determination was made for all of the items in the EMEC stock-out parts list; this second rate was calculated from the 10550-1/4855 report data. The calculated rates were then compared to the previously assigned rates and the larger of the two rates was selected for use in the program. No calculation was made for items having less than three replacements reported. The list of items considered is given in table 2 with the rates from both sources. Items for which no calculation was made are shown with zero rate in the 10550 column.

A replacement rate was also calculated from the data in the ARINC report for all items listed therein as having more than three replacements. This rate was also compared to the initially assigned rate with the higher rate being selected for final use. The results of these comparisons are given in table 3.

Finally, a demand rate was calculated for the parts peculiar using the demand data supplied by ESO. The resulting demand rates were compared to the established replacement rates and the following action taken:

a. Replacement rate changed to equal 75% of calculated demand rate if the calculated demand rate exceeded the replacement by one order of magnitude, and if the original source of the replacement rate was neither Technical Note 1744.00-2 nor NAVSHIPS 93820.

TABLE 2. AN/SPS-40 STOCK-OUT PARTS(10550/4855 REPLACEMENT RATES)

FSN or Part No.	Circuit Symbol	Replacement Rate From Publications	Replacement Rate From 10550/4855 Data
5840-713-5639	3Z4	10.00*	0.97
5840-732-8505	2A2	28.56*	3.22
5840-976-3268	6A4Z1	0.10	0.32*
5915-713-5366	3Z3	3.00	3.50*
5935-731-1876	6A3XV2	0.062	1.29*
5935-731-1885	6A3XV1	0.062	0.97*
5935-860-0824	6A2XV1 6A2XV2 6A2X[illegible]	0.062*	0.00
5950-838-3074	3[illegible]	0.40	0.97*
5960-583-4396	4V1	144.00*	9.66
5960-813-1525	5A6V1 5A6V2	35.00*	1.06
5960-819-2275	6A3V1 6A3V2	144.00*	18.11
6110-733-5277	12A3A3L1	7.00*	0.32

*Indicates rate used as program input.

TABLE 3. AN/SPS-40 STOCK-OUT PARTS(ARINC REPLACEMENT RATES)

FSN or Part No.	Circuit Symbol	Replacement Rate From Publications or Table 2	Replacement Rate From ARINC Data
5935-731-1876	6A3XV2	1.29**	131.48*
5950-732-8525	4T2	1.38	75.14*
5950-838-3074	3L3	0.97**	56.35*
5960-262-0195	5A8V5 5A8V7	35.00*	1.83
5960-295-7477	5A12V2 5A12V3 5A12V4	35.00	42.26*
5960-577-6214	6CR5 6CR6 6CR7 6CR9	3.30	3.61*
5960-583-4396	4V1	144.00*	131.48
5960-644-2892	6A2V1 6A2V2 6A2V3	144.00*	137.76
5960-731-1744	23A8V1 23A8V2 3V1 3V2	144.00*	101.44
5960-810-2763	22A2Q1 22A3Q1 22A3Q2	1.50	28.18*
5960-813-1525	5A8V1 5A8V4 5A12V5 5A6V1 5A6V2 5A6V3	35.00	165.53*
5960-815-0813	6A2V4 6A2V5	58.74	112.68*
5960-819-2275	6A3V1 6A3V2	144.00*	140.85
5960-840-3561	5A30Q3 5A30Q19 5A30Q21	1.50*	0.65
5960-892-0796	3V5	144.00*	95.71
5970-848-8455	6A2C24 6A2C30	0.29	37.57*

*Indicates rate used as program input.

**Indicates rate from table 2.

b. Item listed as suspected misapplication if calculated demand exceeded replacement rate by one order of magnitude and original rate source was either Technical Note 1744.00-2 or NAVSHIPS 93820.

c. No action taken if demand rate did not exceed replacement by one order of magnitude. There were no demand rates which exceeded the replacement rates by one order of magnitude. The demand data was, therefore, reduced to the role of supporting the decision made to select the replacement rates determined from the 10550/4855 data shown in table 2. There were no demand rates used in this analysis directly.

6. The final step in the development of the program input consisted of the preparation of punch cards containing all of the items established in the preceding steps. The cards were tabulated and a final check made of all entries to insure that accurate input data were available for the computer operation.

A total of 2,178 data cards were made for the computer run. This total was broken down by essentiality code as follows:

Code 1 - 1,772 cards

Code 2 - 24 cards

Code 3 - 361 cards

Code 4 - 21 cards

All of the 2,178 cards representing the 10,151 circuit symbols in the AN/SPS-40 Radar are identified by either a Federal Stock Number of which there were 1,839 or a manufacturer's number of which there were 339. Only 91 of the 1,839 Federal Stock Numbers lack a weight, cost, or cube, while 333 of 339 manufacturer's numbers lack a weight, cost, or cube. All cards have part name, population, replacement rate and code.

Section IV
COMPUTER PROGRAM

The underlying mathematical approach utilizes the Poisson probability function which is

$$P(x) = \frac{(N\lambda t)^x \, e^{-N\lambda t}}{x!}$$

where: $P(x)$ = Provisioning probability

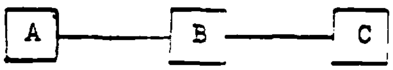
N = Part type population

λ = Replacement rate per 10^6 operating hours per part type

t = Average operating hours per calendar stock period

x = Stock quantity

In order to illustrate the steps necessary to determine the stock quantities, assume a simple equipment consisting of three part types called A, B, and C. In diagram form this example would be represented as shown below.



Using the Poisson probability function, the probability for each part type surviving time t without replacement, or in other words for X = 0, is calculated. If this operation yielded, for example:

A = .904

B = .818

C = .906

then, according to the model, the equipments' probability of surviving with no spares would be A x B x C = .904 x .318 x .906 = .670.

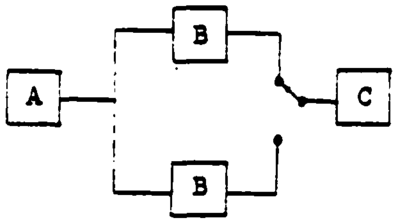
The .670 is called the provisioning level of the equipment. The procedure then calls for selecting the part with the lowest chance of surviving without back up which in the example above is B = .818. One part of type B is stocked and the probabilities of the part type recomputed which now produces

A = .904

B = .982

C = .906

The model would be as follows:



The probability of the equipment surviving with one spare for B would be A x B x C = .904 x .982 x .906 = .804. If the provisioning goal for the equipment were 80% the problem would be solved with one back up item for part type B. In the case of the AN/SPS-40 there were 2,178 part types being considered during generation of the first stock list and each of the part type probabilities were calculated to eight places. Due to the magnitude of the mathematical operations the process was computerized.

The computer program developed during Phase I of this study requires approximately one hour run time to perform the needed 20,000,000 mathematical operations. The program has been written in Fortran II for an IBM 7090 computer.

INPUT CARDS

In order to run the computer program three types of input cards are necessary; data cards, control card (lead card), and normalized time cards.

The procedures for obtaining the required input data were discussed in Section III. Data obtained were listed on punched data cards in the following format:

Type of Information	Location on Card	Decimal Point Location
FSN or Part Type	1 - 12	-
Part Name	13 - 33	-
Cube (cubic feet)	34 - 41	36
Weight (pounds)	42 - 51	46
Price	52 - 57	Assumed Between 55 & 56
Number of Applications (population)	58 - 61	-
Replacement Rate per 1,000,000 hours	62 - 71	65
Essentiality Code (EC)	72	-
Assembly Part Count	74 - 76	-
SNSL Allowed Part Count	77 - 80	-

Note that all fields on all the cards are right justified.

The control card lists the following type of information according to the computer program symbols:

Symbol	Location on Card	Decimal Point Location	Type of Information
K3	1 - 3	-	Number of normalized time values.
XX	4 - 10	4	Assigned provisioning probability goal for an equipment.
RRR	11 - 16	11	Initial (or Interim) provisioning level (equipment, support ship, or depot) the print out of which is used as peripheral information.
R4	17 - 22	17	Incremental increase in provisioning level of RRR.
R5	23 - 28	23	Assigned provisioning probability goal for a support ship.
R6	29 - 34	29	Assigned provisioning level for depot.
TX1(1)	35 - 43	36	Equipment stock period divided by 1,000,000 where the equipment stock period corresponds to the operating time per calendar time interval (in hours) for which the equipment is being provisioned.
TX1(2)	44 - 52	47	Support ship stock period divided by the equipment stock period where the support ship stock period corresponds to the calendar time interval (in hours) for which the support ship is being provisioned.

Symbol	Location on Card	Decimal Point Location	Type of Information
TX1(3)	53 - 61	56	Depot stock period divided by the equipment stock period where the depot stock period corresponds to the calendar time interval (in hours) for which the depot is being provisioned.
AS	62 - 65	65	Number of equipments per support ship.
RT	66 - 73	71	The inverse of TX1(3) or $RT = \frac{1}{TX1(3)}$ = normalized time base for replacement of parts.
RTT	74 - 77	77	Total number of equipments divided by the number of equipments per support ship (must be an integer).

The normalized time cards contain the following information:

Symbol	Location on Card(s)	Decimal Point Location
TT_i	Blocks 10 to 70	Positions 4, 12, 24, ..., 64

where i = 1, 2, 3 ..... KB (number of normalized time values)

TT_i must have cumulative values (i.e. 0.01, 0.02, 0.03, 0.10, 0.20, 0.5, 1.0, 2.75, 3.0 ......).

For the computer run the above cards are placed in the following order: the control card first, the normalized time cards second, and the data cards last.

OUTPUT

Computer run outputs are of three types as follows:

1. Output result of one equipment.
2. Output results of support ship.
3. Output results for the depot.

In detail, the output for the equipment, support ship, and depot can be classified by sections.

Section 1. Equipment Part Type and Identification Provisioning Probabilities.

This output contains (1) the provisioning probability for equipment, (2) the part or part type (FSN) provisioning probability, (3) the spare requirements associated with the part or part type and, (4) the total number of spares.

Section 2. Provisional Probability Function (Provisioning Probability vs Stock Periods).

The output for this section is a point cumulative provisional probability function versus stock periods. The output of this section supplies a sufficient number of points to draw a provisioning probability curve with the stock period as a variable.

Section 3. FSN Identification, FSN, EC, Cube, Weight, Cost and Spares per FSN.

The output of this section is as follows:

1. Part type (FSN) identification number. These values range

sequentially from 1, 2, 3 ...., r (the number of different part types). The purpose of this output is to associate the provisional probability of Section 1 above with the associated FSN numbers of Section 3.

2. Part type (FSN).

3. Essentiality Code number (EC) assigned each FSN. These rating codes are classified as follows:

Code #1 - Critical and shipboard installable spare part type.

Code #2 - Critical and not shipboard installable spare part type.

Code #3 - Noncritical and shipboard installable spare part type.

Code #4 - Noncritical and not shipboard installable spare part type.

4. Nomenclature of FSN.

5. Total cube per FSN for the specified spares for equipment, support ship, or depot.

6. Total weight per FSN for the specified spares for equipment, support ship, or depot.

7. Total price per FSN for the specified spares for equipment, support ship, or depot.

8. Replacement rate per part type for equipment, support ship, and depot. The replacement rate for the support ship is based upon the number of equipments serviced and the replacement rate for the depot is dependent upon the total number of equipments serviced.

9. Part type applications (population) per single equipment.

10. Spare requirements (per equipment, support ship, or depot).

11. Replenishment spares per part type (FSN). This value is

obtained by multiplying item (8) by item (9) and dividing by quantity 2. If the result is greater than 0.5 the integer portion of replenishment spare requirements is raised by one, otherwise it is truncated. This type of spare requirement is printed as an output for the depot only.

12. Sum of standby spares [item (10) above] and replenishment spares [item (11) above] per FSN. This is printed out for the depot only.

Section 4. Provisioning Probabilities versus Cube, Weight, and Cost.

The output for this section is an approximate 0.01 cumulative probability increment versus cumulative price, cube, and weight. The output of this section supplies sufficient points to draw provisioning curves for price, cube, and weight up to the probability goals set for the equipment, support ship, and depot. These provisioning probability goals are dependent upon their respective provisioning calendar times.

VARIABLE PARAMETERS

Changes in the variable parameters are made by adjustment of a control card.

The computer program for generating spare part requirements for equipments, support ship, and depots is based upon Poisson functions. Efforts have been made to make the computer program general in nature. This has been accomplished by allowing the parameters of stock period (t) and provisioning probabilities to vary. A general description of how these parameters are allowed to vary is as follows:

1. An overall protection goal (provisioning probability) may be assigned to equipments, support ship, and depots by properly punching the control card.

2. Another variable introduced into the computer program allows for the print out of spare parts requirements for equipments, support ship, and depot at a <u>prescribed provisioning probability level</u>. In addition, print outs of spare parts for equipment, support ship, and depot can be printed out at prescribed cumulative increments (0.01, 0.05, 0.10, etc.). For example, the overall provisioning goal for an equipment may be 0.90. However, it may be desired to print out the spare requirements at a provisioning level of 0.65 with increments of 0.10. By punching the input card properly for a computer run, a print out may be obtained which lists part types and their associated spare parts at provisioning levels of 0.65, 0.75, 0.85 and 0.90.

3. The stock period has been allowed to be a variable in the computer program. As a result, points for a provisioning probability function (for equipments and support ships versus normalized time) can be generated. For example, having set the provisioning probability goal for an equipment (i.e., 0.99) for a specified stock period (i.e., 2190 hours), a range of provisioning probabilities can be calculated by varying time. The provisioning probability function for a period of 2190 hours may print out as follows:

Provisioning Probability	Normalized Time
.99982	.10
.99965	.20
.99757	.40
.99532	.60
.99320	.80
.99001	1.00
.96002	1.20
.88217	1.40
.80000	1.60
.69021	1.80
.58214	2.00
.31191	2.50
.13210	3.50
.01307	4.00
.00092	4.50

The calculation for the print out is truncated when a provisioning probability falls below 0.01. Note that in the example above the provisioning time of the equipment was set at 2190 hours (3 months). The print out was normalized such that 1 = 2190 hours, 0.5 = 1095 hours, and 2 = 4380 hours.

4. Another dimension of the time (τ) variable is concerned with the replenishment of parts. The replenishment of parts as such is considered to be a function associated with the depot. Dependent upon the calendar hours considered, the replenishment of spare parts per part type (FSN) are calculated and listed.

Replenishment rates are based upon the assumption of a constant failure rate per part type. It is stipulated that the depot replenishes spare parts for all equipments and, as a result, the spares for replenishment are calculated for that location only.

BLOCK DIAGRAM

The information represented on the lead card and the data cards are processed by the computer. The block diagram of figure 3 represents functional operations by which the output described is derived.

Symbols not defined that are included in the block diagram are:

- λ - replacement rate per part type
- t - stock period (hours)
- N - number of applications or population of part type in an equipment
- X - number of spares per part type
- RR - an interim provisioning probability used to reach assigned probability goals such as XX

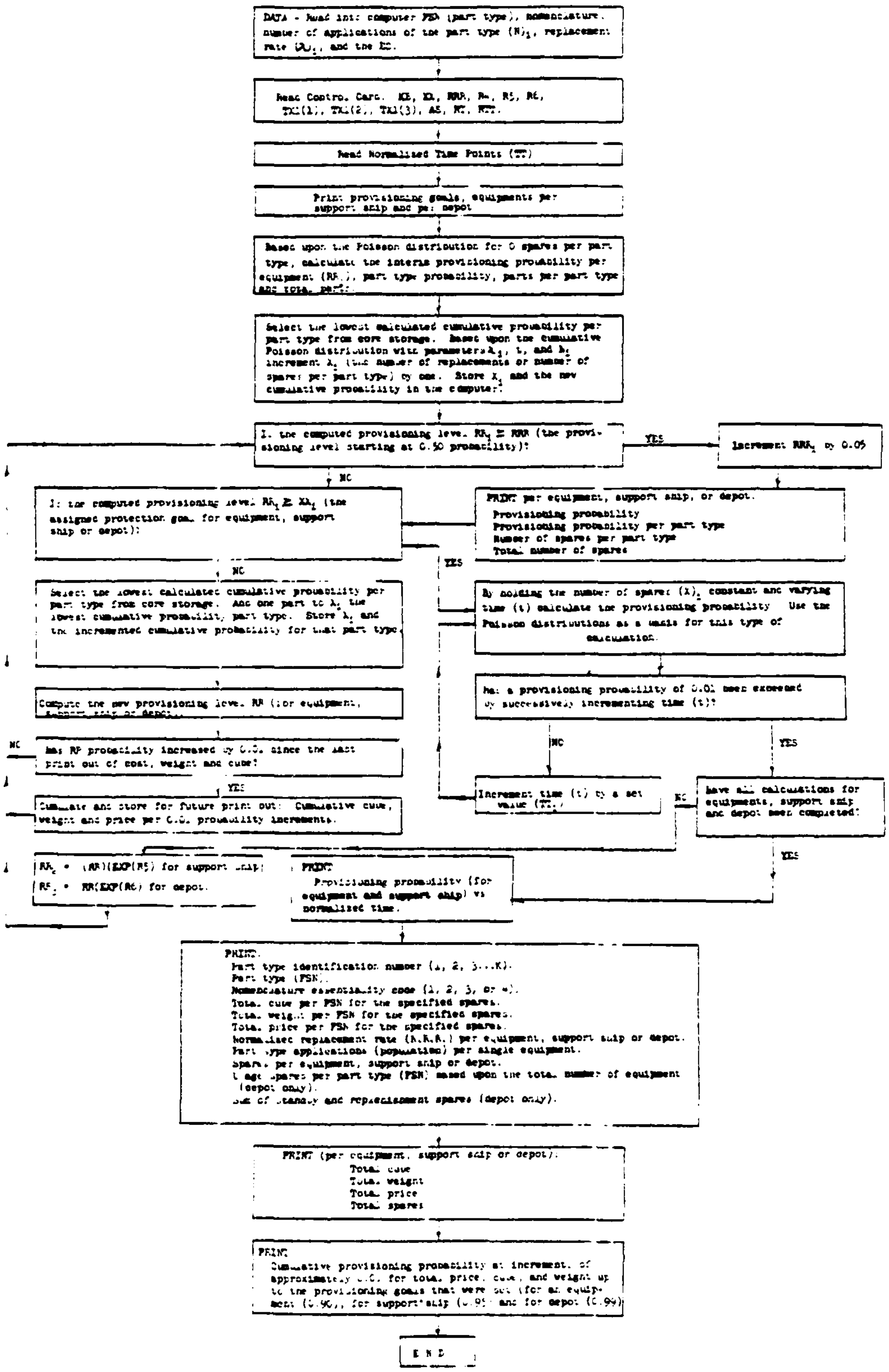


Figure 3. Computer Program Block Diagram

MATHEMATICAL MODEL

The mathematical methodology for determining spare parts requirements delineates the computational processes involved. Associated with each part type is a probability for a specified time (t) that not more than K spares will be required. This probability is calculated according to the function:

$$P(X) = \sum_{X=0}^{k} \frac{(N\lambda t)^X e^{-N\lambda t}}{X!} \qquad (1)$$

Where:

$P(X)$ = provisioning probability per part type

λ = replacement rate per 1,000,000 hours per part type

t = calendar time (in hours)

N = number of applications or population per part type per equipment

X = number of spares (index of summation)

e = natural logarithm base

k = total number of spares per part type representing items installable at the equipment site

There are as many $P(X)$ calculations as there are different part types.

For analytical purposes part types in an equipment are considered to be in series. As a result the following equation applies:

$$P(X_s) = (P(X_1) \cdot P(X_2) \cdot P(X_3) \;.....P(X_r)) \qquad (2)$$

or

$$P(X_s) = \prod_{i=1}^{r} P(X_i) \qquad (3)$$

or

$$P(X_s) = \prod_{i=1}^{r} \left(\sum_{X_i=0}^{k_i} \frac{(N\lambda)_i t^{X_i} e^{-(N\lambda)_i t}}{X_i!} \right) \qquad (4)$$

Where:

r = number of different part types

$i = 1, 2, 3, \ldots\ r$ (part types)

$P(X_s)$ = provisioning probability for an equipment or system

In order to meet a provisioning goal for an equipment the following procedure which incorporates the standby concept for spare part provisioning was followed.

The probability $P(X_i)$ associated with each part type with no spares was calculated and stored in the computer. The provisioning level for the equipment was then calculated following the criterion:

$$P(X_G) \leq P(X_s) \qquad (5)$$

Where: $P(X_G)$ = the provisioning goal for an equipment.

During the computer run, if the calculated probability $P(X_s)$ is less than that assigned as a goal for an equipment, each part type is scanned to determine which has the lowest probability. The part type that has the lowest survival probability is selected and a spare is added to that part type; that is, X_i (spares) is increased by one (1). Subsequently $P(X_s)$ is recalculated. If $P(X_G) \geq P(X_s)$, the part type probabilities are again scanned to select the lowest probability. The above procedure is followed until $P(X_G) \leq P(X_s)$. The spares associated with each part type probability $P(X_i)$ are retained in storage in the computer to be printed out at a later time. These spares $\left(\sum_{i=1}^{r} X_i\right)$ represent the requirements for an equipment based upon the provisioning probability goal $P(X_G)$ and specified stock period (t).

In order to calculate the spare requirements for the support ships the following mathematical model was considered:

$$P(X_T) = \prod_{i=1}^{r'} \left[\sum_{X_i=0}^{k_i''} \frac{\left[(N'N\lambda)_i t\right]^{X_i} e^{-(N'N\lambda)_i t}}{X_i!} \right] \tag{6}$$

Where:

N' = number of equipments per support ship

r' = total number of part types (items that are shipboard installable)

k_i'' = number of spares of a part type

The above model can be grouped in the following manner

$$P(X_T) = \prod_{i=1}^{r'} \left\{ \sum_{X_i=0}^{k_i'} \frac{\left[(N'N\lambda)_i t_j\right]^{X_i} e^{-(N'N\lambda)_i t_j}}{X_i!} + \sum_{X_i=k_i'+1}^{k_i''} \frac{\left[(N'N\lambda)_i t_j\right]^{X_i} e^{-(N'N\lambda)_i t_j}}{X_i!} \right\} \tag{7}$$

where $k_i' \leq k_i''$

t_j = calendar time at provision location (equipment, support ship, depot)

$j = 1,2$

The provisioning probability level for a part type in an equipment can be represented by

$$P(X) = \sum_{X=0}^{k} \frac{(N\lambda t)^X e^{-N\lambda t}}{X!} \tag{8}$$

The provisioning level for the same part type in a number of equipments (represented by a support ship) is

$$P(X') = \sum_{X=0}^{k'} \frac{(N'N\lambda t)^{X'} e^{-N'N\lambda t}}{X!} \tag{9}$$

In the above equation for a part type, index X such that the total spares (k') generates a probability $P(X') \leq P(X)^{N'}$ (provisioning probability of the support ship with 0 spares). Since the Poisson distribution is discrete, the cumulative probability $P(X')$ is incremented to k' until it is equal to or just below the probability $P(X)^{N'}$.

The provisioning probability afforded to the support ship by having spares at the equipment site can be represented by

$$\prod_{i=1}^{\ell} P(X_i)^{N_i'} \cong \prod_{i=1}^{r'} \left\{ \sum_{X_i=0}^{k_i'} \frac{\left[(N'N\lambda)_i t_j\right]^{X_i} e^{-(N'N\lambda)_i t_j}}{X!} \right\} \tag{10}$$

$\ell = 1, 2 \dots$ the no. of groups of equipments serviced by a tender

The preceding term is the same as the first term of the expression $P(X_T)$ of equation (7). Since this term represents the provisioning probability afforded to the support ship by having spare parts at equipment sites, the associated spares (k') should not be counted. The spare count should start at $k_i' + 1$ and go to k''_i. As a result, the total spares required aboard the support ship would be

$$\sum_{i=1}^{r'} (k''_i - k_i')$$

Spares are added to the support ship based on equation (7) until

$$P(X_T) \geq P(X_G') \tag{11}$$

Where:

$P(X_G') =$ the provisioning goal of the support ship or the protection goal of all of the equipments serviced by the support ship.

The procedure for adding support ship spares was the same as that described for the equipment. After a spare was added a test was made based upon equation (11) until enough spares were added such that the provisioning goal $P(X_G')$ for the support ship was met.

The procedures described for the support ship were applied to the depot as follows:

$$P(X_D) = \prod_{i=1}^{m} \left\{ \sum_{X_i=0}^{S_i'} \frac{\left[(N'N\lambda)_i t_j\right]^{X_i} e^{-(N''N\lambda)_i t_j}}{X_i!} + \sum_{X_i=S_i'+1}^{S_i''} \frac{\left[(N''N\lambda)_i t_j\right]^{X_i} e^{-(N''N\lambda)_i t_j}}{X_i!} \right\} \qquad (12)$$

Where:

$P(X_D) =$ provisioning probability level for all equipments supplied by the depot

$N'' =$ number of equipments supplied by the depot

$m =$ total number of part types (includes items that are shipboard installable and items not installable by ship force)

$S_i'' =$ number of spares per part type at the depot

for provisioning goal

$$P(X_D) \geq P(X_G'') \qquad (13)$$

where

$P(X_G'') =$ provisioning probability goal for the depot.

The number of spares at the depot is represented by $\sum_{i=1}^{m} (SS_i'' - S_i')$.

Spares were added and effects computed by formula (12) until $P(X_D)$ exceeded $P(X_G'')$ at which time the results were printed out by the computer.

It should be noted that the number of part types (m) for the depot is equal to or greater than the number of part types for the support ship or equipment. This is due to the fact that spares at the depot include not only shipboard installable spares but also spares for items which are not shipboard installable.

MODIFICATION METHODS

The computer program was written to develop spare requirements for equipments, support ships, and depot so that the overall provisioning support requirements are established simultaneously. Provisions for developing equipment requirements only, support ship requirements only, or depot requirements only, have not been incorporated in the computer program. However, minor modifications can be readily made to the program to accommodate any such changes in outputs desired. Other modifications may be necessary when changes occur in the equipment configuration, the required provisioning level, or the support philosophy. Specific steps to be followed in such instances are cited in the following paragraphs.

POPULATION CHANGE. If a population change (number of part applications) occurs due to field changes for the AN/SPS-40 Radar the following procedure should be followed for an equipment.

In the computer program output locate the part type population that is to be changed. In the same area locate the replacement rate (NRR - the normalized replacement rate).

Locate the probability P(X) assigned to the part type in question where

$$P(X) \text{ (for the part type)} = \sum_{X=0}^{k} \frac{(N\lambda t)^X e^{-N\lambda t}}{X!}$$

$$\text{or } P(X) = e^{-N\lambda t} + N\lambda t\, e^{-N\lambda t} + \frac{(N\lambda t)^2 e^{-N\lambda t}}{2!} + \ldots + \frac{(N\lambda t)^k e^{-N\lambda t}}{k!}$$

Where:

N = population or number of applications of a part type

λ = replacement rate

k = number of spares required

Use the above equation, substituting N', the revised population, for N, the replaced populations, and solve for several values of k' (the revised number of spares that may be different from k) such that $P(X')$'s span P(X).

$$P(X') = e^{-N'\lambda t} + N'\lambda t\, e^{-N'\lambda t} + \frac{(N'\lambda t)^2 e^{-N'\lambda t}}{2!} + \ldots\ldots$$

$$+ \frac{(N'\lambda t)^{k'} e^{-N'\lambda t}}{k'} \cong P(X)$$

Where:

$P(X')$ = revised probability based on N' for the part type in question

N' = the new population or total number of applications

k' = the sought for spare requirements for a part type

The following example is based upon the output of the computer run for the SPS-40.

Consider part type (FSN) number 54 in the print out for an equipment where

N.R.R. (λ)	Pop. (N)	Spares (k)	$U=\lambda N$	$\sum_{X=0}^{k} \frac{(\lambda N)^X e^{-\lambda N}}{X!}$
.001150	1	1	.001150	$\frac{k=1}{.99999934}$

Consider that the population has changed to 2 (then $N'=2$)

N.R.R. (λ)	Pop. (N')	Spares (k')	$U'=\lambda N'$	$\sum_{X=0}^{k'} \frac{(\lambda N')^X e^{-\lambda N'}}{X!}$
.001150	2	Unknown	.002300	$\frac{k'=1}{.99999736}$
				$\frac{k'=2}{.99999999}$

Since .99999999 is closer to .99999934 (actual print out value for FSN #54) than .99999736, $k'=2$ for the new number of spares to replace k=1 (the old number of spares) and $N'=2$ for the new population to replace N=1 (the old population).

The procedures applicable to population changes can also be applied to replacement rate (λ) changes. The calculations to determine the required spare parts are similar to the example above.

Adjustments required by a field change will usually consist of adding new part types and their associated replacement rates or changing the part population. Determination of the required spares can be made by applying procedures similar to those described in the example above.

PROVISIONING LEVEL CHANGE

In order to vary the provisioning probability level for spare requirements for (1) equipment, (2) support ship and, (3) depot, it is necessary to rerun the computer program with the proper changes in the lead card. For example, suppose the provisioning probability goal for equipment, support ship, and depot had been 0.90, 0.95, and 0.99 respectively and it was desired to change the provisioning probability goals to 0.95, 0.90, and 0.999 respectively. The only requirement would be to punch the lead card properly as follows:

Symbol	Location on Card	Decimal Point Location	Punched Numbers
XX (for equipments)	4 - 10	4	.95 (in columns 4 - 6)
R5 (for support ship)	23 - 28	23	.90 (in columns 23 - 25)
R6 (for depot)	29 - 34	29	.999 (in columns 29 - 32)

EQUIPMENTS PER SUPPORT SHIP CHANGE

In order to vary the number of equipments per support ship and the number of equipments per depot, the computer program would have to be rerun. For example, consider a case where four (4) ships on the average are to be serviced by a support ship and there are a total of fifty-six (56) ships. Then, it would be necessary to punch the lead card properly. The follc ng fields would have to be repunched on the lead card:

Symbol of Field	Location on Card	Decimal Point Location	Required Change
AS (equipments per support ship)	62 - 65	65	4. (in columns 64-65)
RTT (total equipments ÷ equipments per support ship)	74 - 77	77	9. (in columns 76 - 77)

STOCK PERIOD CHANGE

In order to vary the stock period for equipment, support ship, and depot the computer program would have to be rerun. For example, consider the case where the stock periods for the equipment are 2,000 hours, for the support ship 4,000 hours, and for the depot 3,000 hours. On the lead card of the computer program the following fields would have to be changed:

Symbol of Field	Location on Card	Decimal Point Location	Required Change
TX1(1)	35 - 43	36	.002 (locations 36 - 39)
TX1(2)	44 - 52	47	2.0 (locations 46 - 48)
TX1(3)	53 - 61	56	1.5 (locations 55 - 57)

NORMAL USAGE PERIOD CHANGE (DEPOT)

Theoretically, the purchase of parts for normal usage is considered to be done only at one source, namely, the depot. Varying the average usage of parts would require punching the lead card properly, since the usage time for parts at the depot is dependent upon item TX1(3) (the depot stock period divided by the equipment stock period). The assumption has been made that each part type has a constant failure rate and as a result parts are assumed to be reordered on that basis. If, for example, parts are reordered on the average of every 700 hours, punch the listed field of the lead card in the following manner:

Symbol of Field	Location on Card	Decimal Point Location	Required Change
RT	66 - 73	71	.43 (locations 71 - 73)

Note from the preceding example that TX1(3) is 1.5 (3,000 hours ÷ 2,000 hours). The usage time for parts at the depot (RT) is dependent upon item TX1(3) and RT (with a value of 0.43) is obtained by dividing 3,000 by 700.

The results obtained during this program have been generated through the use of the mathematics presented in this section. The actual calculations were performed on a 7090 computer. The computer program has been developed with the realization that each new evaluation will likely have a unique set of conditions and parameters. The computer program therefore has been made versatile in order to properly handle future requirements.

Section V
PHASE I RESULTS

Results of the Phase I effort establish provisioning criteria for an equipment, a support ship, and a depot. For each of these provisioning locations there are four results which are (1) calculations, (2) spare parts stock list, (3) provisioning level versus stock period, and (4) weight, cost, and cube constraints.

The calculations with accompanying print outs have not been included in this report due to the volume of the material and the fact that it is useful primarily as a reference. The equipment calculation section showing the provisioning levels of 50%, 55%, 60%, 65%, 70%, 75%, 80%, 85%, and 90% for the equipment has been forwarded along with the calculations for the support ship and depot under separate cover. The results of the remaining sections are presented below. Because of the size of some tables, they have been included in a separate volume entitled Appendix A.

The following tables are included in Appendix A:

- A-1 Equipment Critical/Noncritical Parts Stock List
- A-2 Equipment Critical Parts Only Stock List
- A-3 Equipment Critical Parts (Minimum Depth) Stock List
- A-4 List of Critical Part Types Assigned (to A-3) One Part
- A-5 Equipment Critical/Noncritical Parts and Assemblies Stock List
- A-6 List of Critical Item Types Assigned (to A-5) One Item
- A-7 Support Ship Stock List - Parts Only

A-8 Support Ship Stock List - Parts and Assemblies

A-9 Depot Stock List - Parts Only

A-10 Depot Stock List - Parts and Assemblies

EQUIPMENT STOCK LIST (CRITICAL/NONCRITICAL PARTS)

The stock number sequence list derived in this program is for the AN/SPS-40 Radar only and, therefore, corresponds approximately to the stock number sequence list as presented in the AN/SPS-40 Allowance Parts List. The criterion followed in determining the sequence in which parts are considered for sparing is to select the part which indicates the highest likelihood of requiring replacement. The critical/noncritical parts stock list yields a provisioning level of 90% for the equipment's code 1 and 3 parts for a 90-day stock period.

While the 90% protection level means that only one time out of ten will the equipment experience a stock-out during a 90-day period without replenishment, it must be recognized that the 90% protection level is for only those parts considered, namely, code 1 and 3 parts which are critical and noncritical parts that are installable by a ship's force. The equipment also contains code 2 and 4 parts which are critical and noncritical parts that are not installable by a ship's force and, therefore, not stocked at the equipment site.

It was necessary to omit code 2 and 4 parts from the initial probability calculations for zero spares because it has been determined that about eight times out of a hundred an AN/SPS-40 will require a code 2 or 4 part during a 90-day period. This means that if all codes were considered in the analysis of the equipment, it would initially have a 92% provisioning level ceiling due to the code 2 and 4 parts for which no amount of

stocking of code 1 and 3 parts could change. Then, if the equipment is to be protected to a 90% level, the code 1 and 3 parts must be stocked in such quantity that only one time out of a hundred will the equipment experience a stock out of code 1 or 3 parts. Under such conditions the code 1 and 3 parts must be heavily stocked because of the penalty involved in having 2 and 4 parts in the equipment initial provisioning calculation. While this type of stocking can be performed by the program if desired, it is considered to be unrealistic and requires far too great a stocking of code 1 and 3 parts with negligible advantage. The program, therefore, stocks to a 90% level for the equipment under the criterion that the parts must be code 1 or 3 to be considered.

If all parts within the equipment are considered, namely codes 1, 2, 3, and 4, it can be determined from the above figures that an equipment would experience an unfilled spare part requirement about seventeen times out of every 100 three-month stock periods where about seven of these would be due to the code 1 and 3 parts.

The critical/noncritical parts provisioning list is shown in table A-1. This list was generated under the criterion that all code 1 and 3 repairs would be performed by Navy technicians. All part types considered in the analysis are listed in the print out whether spare parts are recommended or not. The format is as follows:

Column #1 - The code numbers shown are arbitrarily assigned to allow tracing the part type in the calculation tabulations.

Column #2 - The part identification number is shown in column 2. In most cases this number is the Federal Stock Number. Those without FSN's are listed by manufacturer's number. The listing is in numerical

order in this column with FSN's first, followed by manufacturer's numbers.

Column #3 - This column shows the essentiality code number of the parts where

1 = installable by ship's force and critical,

2 = not installable by ship's force and critical,

3 = installable by ship's force and noncritical, and,

4 = not installable by ship's force and noncritical.

Column 3 contains only code 1 and 3 parts since this listing is for provisioning the equipment and, therefore, contains only those parts installable by the ship's force. The critical and noncritical parts have both been shown in the listing with the critical parts first followed by the noncritical parts. If it is desired to provision only the critical parts then code 3 spares should be deleted from the list.

Column #4 - A brief name for the part type is presented in this column.

Column #5 - The cube shown in this column represents the packaged cube for the number of spares shown in Column 10. For example, if a resistor with an FSN 5905-000-1111 had a package cube of 0.00025 cubic feet each and if four spares were recommended in column 10 for stocking aboard ship, then column 5 would show 4 x 0.00025 = 0.001 cubic feet since this is the volume of all the spares of the listed type. Column 5 is totaled on the final line of the listing to show the combined total cube of all the spares recommended by the stocking procedure.

Column #6 - This column contains the package weight in pounds for the number of spares shown in column 10 for the part type. The weights are also totaled to represent the gross weight of the recommended spares.

Column #7 - The combined price of the number of spares shown in column 10 is printed in column 7. The prices are also totaled to give the price of the recommended total spares.

Column #8 - The title NRR of this column means "normalized replacement rate" which is the part type replacement rate per 90 days where the 90 days corresponds to the stock period selected for this provisioning list.

Column #9 - Column 9 shows the number of applications of the part type per equipment within the code class of column 3. There may be a total equipment population of the part type greater than shown in column 9 if the part type has more than one code class assigned to it. In order to determine total equipment population of a part type it is necessary to sum all the applications of the part type for the four code classes. Code 2 and 4 parts will be found only in the depot listing.

Column #10 - The quantity of recommended spares per part type is shown in column 10. The sum shown for this column is the total number of parts recommended for provisioning at the 90% level for the AN/SPS-40 Radar for a 90-day stock period. The critical/noncritical parts list recommended a range of 1,809 part types and a total depth of 2,103 parts which have a total value of 174 cubic feet, a total weight of 1,472 pounds, and a total cost of $78,058.00.

EQUIPMENT STOCK PERIOD VARIATION

The critical/noncritical parts provisioning list presented above was the number of spares required to support an equipment at the 90% level for a 90-day stock period. Since all provisioning periods may not conform to 90 days duration, the question arises as to what is the level if the stock period is altered with the recommended provisioning list unchanged.

Table 4 furnishes the information required to determine the provisioning level as a function of stock period. The first column gives the provisioning level. The second column presents the stock period which has been normalized on the basis of 90 days or 1.00 is equal to 90 days. Likewise 2.00 is equal to 180 days, 3.00 is equal to 270 days, etc. Each tenth (0.1) is equivalent to approximately 9 days. These two columns of data points have been plotted in figure 4. A possible application of this graph would be the situation where the 90% provisioning level has been stocked for the equipment for an anticipated 90-day cruise; however, due to an emergency, it is found that the cruise time will be extended to 150 days. The graph shows the provisioning level under such a cruise condition would be 62% instead of 90%.

TABLE 4. EQUIPMENT STOCK PERIOD VARIATIONS - CRITICAL/NONCRITICAL PARTS

Provisioning Level	Normalized Time (90 days = 1.00)
0.99481	0.08
0.99413	0.09
0.99344	0.10
0.98624	0.20
0.97839	0.30
0.96982	0.40
0.96052	0.50
0.95042	0.60
0.93944	0.70
0.92749	0.80
0.91443	0.90
0.90008	1.00
0.89704	1.02
0.89394	1.04
0.89077	1.06
0.88754	1.08
0.88424	1.10
0.88087	1.12
0.87743	1.14
0.87391	1.16
0.87031	1.18
0.86664	1.20
0.85707	1.25
0.84694	1.30
0.83620	1.35
0.82480	1.40
0.81270	1.45
0.79984	1.50
0.77167	1.60
0.70453	1.80
0.62229	2.00
0.42354	2.40
0.22694	2.80
0.09085	3.20
0.02632	3.60
0.00544	4.00

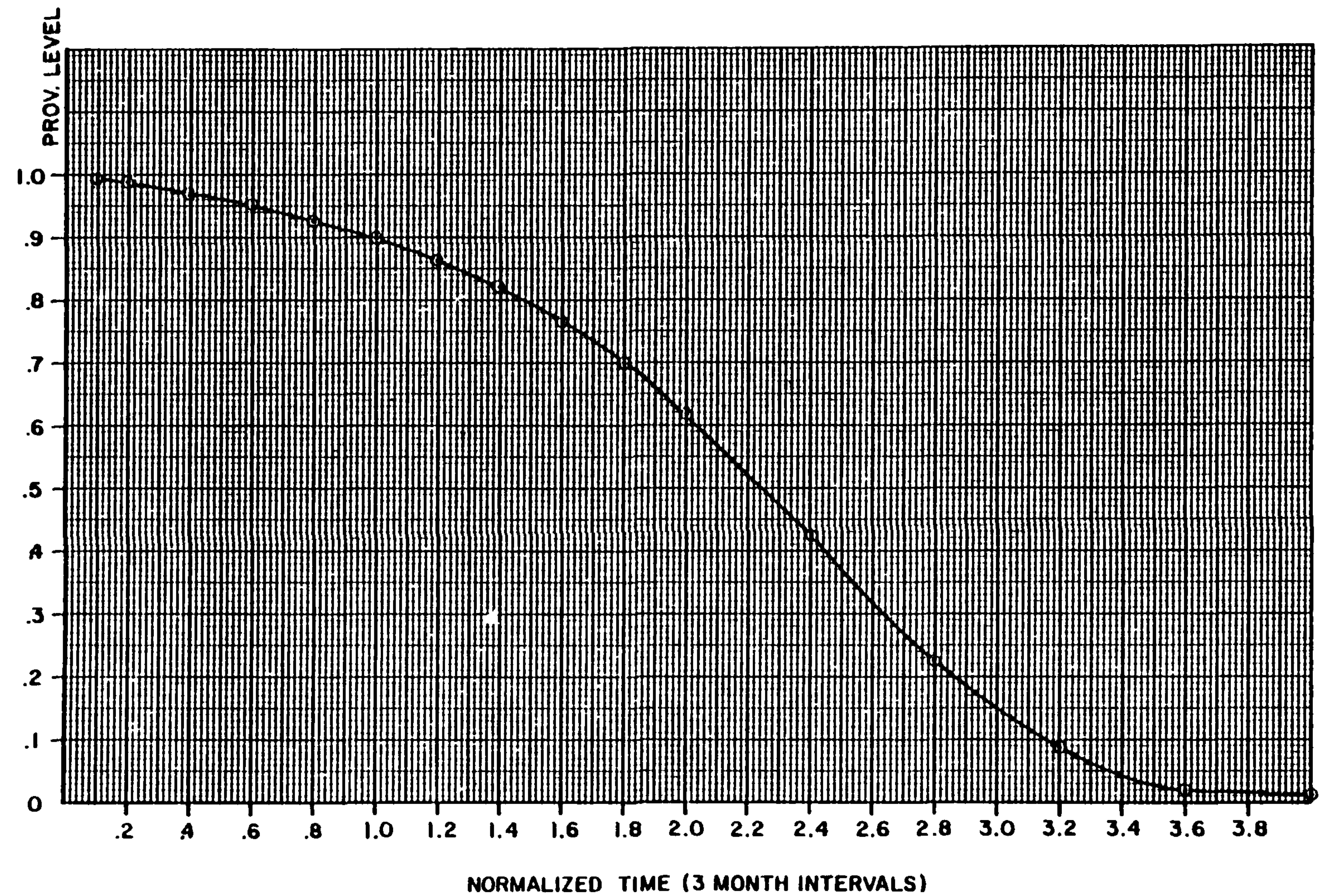


Figure 4. Equipment Stock Period Variation Graph - Critical/Noncritical Parts

EQUIPMENT STOCK CONSTRAINTS

The range and quantity of spare parts only was determined previously for the 90% provisioning level since this value was decided upon as the desired goal for the equipment. Once having determined the stock list however, it may be found to be impossible or impractical to use because the recommended spares are too heavy, too expensive, or require too much storage space. The following table presents the next best solution to the problem if one of the above constraints makes the provisioning lists unfeasible. Rather than use a cut and try procedure with the calculations in order to find an acceptable stock load, the governing constraint is located in table 5 and the associated provisioning level is read directly in column 1. It is then necessary to recompute the stock list to find the exact range and depth of spare parts associated with the provisioning level obtained from the table. Column 1 is the provisioning level. Column 2 is the price of the load, and columns 3 and 4 are the cube (in cubic feet) and weight (in pounds) of the load respectively. An exponent format has been used in columns 2, 3, and 4 since it is anticipated that large numbers may be presented in this type of table. The exponent format is a shorthand method of changing the magnitude of the values, for example:

$$0.400000 \text{ E} + 02 \text{ is the same as } 0.400000 \times 10^2 \text{ or } 40.0000$$

By simple rule of thumb the decimal point is moved as many places to the right as shown by the number following the "E". If the "E" is followed by a minus sign, then the decimal point is moved as many places to the left as the number shown following the "E". The constraints are also shown graphically in figure 5.

TABLE 5. EQUIPMENT STOCK CONSTRAINTS - CRITICAL/NONCRITICAL PARTS

Provisioning Level	Price	Cube	Weight
0.010071	0.412905E 05	0.697545E 02	0.574649E 03
0.020085	0.465425E 05	0.757770E 02	0.693869E 03
0.030174	0.470470E 05	0.761794E 02	0.710609E 03
0.040391	0.486092E 05	0.110429E 03	0.750925E 03
0.050430	0.494900E 05	0.110952E 03	0.765695E 03
0.060436	0.504146E 05	0.111707E 03	0.782604E 03
0.070799	0.509401E 05	0.112006E 03	0.795794E 03
0.080828	0.510684E 05	0.112471E 03	0.804464E 03
0.090842	0.510927E 05	0.112505E 03	0.806744E 03
0.101047	0.511210E 05	0.112540E 03	0.808004E 03
0.111342	0.513013E 05	0.113198E 03	0.820854E 03
0.121687	0.587824E 05	0.116410E 03	0.825344E 03
0.131836	0.591764E 05	0.116813E 03	0.837924E 03
0.142164	0.591906E 05	0.116827E 03	0.840754E 03
0.152246	0.596365E 05	0.117048E 03	0.850614E 03
0.162769	0.599681E 05	0.117221E 03	0.858994E 03
0.172942	0.599972E 05	0.117323E 03	0.861664E 03
0.183130	0.600255E 05	0.117419E 03	0.864194E 03
0.193265	0.609368E 05	0.117877E 03	0.866154E 03
0.203811	0.610268E 05	0.117911E 03	0.867354E 03
0.213853	0.616284E 05	0.118151E 03	0.872794E 03
0.224483	0.617309E 05	0.118238E 03	0.881183E 03
0.235091	0.666414E 05	0.118347E 03	0.887183E 03
0.245253	0.666445E 05	0.118350E 03	0.889013E 03
0.255622	0.667780E 05	0.118391E 03	0.890993E 03
0.266124	0.669701E 05	0.118490E 03	0.899763E 03
0.276810	0.670557E 05	0.118572E 03	0.903123E 03
0.286915	0.673447E 05	0.153780E 03	0.905223E 03
0.297452	0.673842E 05	0.153884E 03	0.910503E 03
0.307844	0.674129E 05	0.153902E 03	0.911233E 03
0.318001	0.674233E 05	0.153921E 03	0.912073E 03
0.328493	0.674468E 05	0.153939E 03	0.912913E 03
0.338546	0.674848E 05	0.153988E 03	0.914133E 03
0.348860	0.675546E 05	0.154039E 03	0.915413E 03
0.359139	0.676634E 05	0.154098E 03	0.917493E 03
0.369709	0.676954E 05	0.154143E 03	0.920123E 03
0.380407	0.677156E 05	0.154254E 03	0.923439E 03
0.390525	0.679141E 05	0.154325E 03	0.927229E 03
0.400913	0.679141E 05	0.154325E 03	0.927229E 03
0.411509	0.684463E 05	0.154341E 03	0.927579E 03
0.421551	0.688979E 05	0.154949E 03	0.932739E 03
0.431619	0.691903E 05	0.154970E 03	0.934069E 03
0.441666	0.692051E 05	0.155004E 03	0.935479E 03
0.451753	0.692061E 05	0.155009E 03	0.936919E 03
0.462069	0.692103E 05	0.155013E 03	0.938269E 03
0.472621	0.692112E 05	0.155016E 03	0.939769E 03
0.483158	0.727197E 05	0.163608E 03	0.124056E 04

TABLE 5. EQUIPMENT STOCK CONSTRAINTS - CRITICAL/NONCRITICAL PARTS (Continued)

Provisioning Level	Price	Cube	Weight
0.493447	0.727478E 05	0.163656E 03	0.124167E 04
0.504070	0.729054E 05	0.163737E 03	0.124504E 04
0.514096	0.729863E 05	0.163835E 03	0.125396E 04
0.524137	0.730836E 05	0.164504E 03	0.125978E 04
0.534631	0.731114E 05	0.164550E 03	0.126158E 04
0.544826	0.731803E 05	0.164586E 03	0.126496E 04
0.555501	0.733657E 05	0.164783E 03	0.127023E 04
0.565531	0.733939E 05	0.164828E 03	0.127128E 04
0.575757	0.734518E 05	0.164889E 03	0.127385E 04
0.585810	0.735287E 05	0.164900E 03	0.127454E 04
0.595856	0.735442E 05	0.165004E 03	0.127877E 04
0.605983	0.736984E 05	0.166255E 03	0.131854E 04
0.616060	0.737286E 05	0.166313E 03	0.132282E 04
0.626675	0.737926E 05	0.166579E 03	0.132794E 04
0.637305	0.738785E 05	0.166659E 03	0.133019E 04
0.647343	0.739236E 05	0.166978E 03	0.133147E 04
0.657539	0.739330E 05	0.166990E 03	0.133195E 04
0.667682	0.741217E 05	0.167140E 03	0.133607E 04
0.677916	0.741942E 05	0.167210E 03	0.133826E 04
0.688396	0.743120E 05	0.167535E 03	0.134641E 04
0.698842	0.743132E 05	0.167542E 03	0.134833E 04
0.709446	0.743154E 05	0.167545E 03	0.135014E 04
0.719534	0.743274E 05	0.167563E 03	0.135200E 04
0.729765	0.743544E 05	0.167571E 03	0.135335E 04
0.740141	0.743555E 05	0.167574E 03	0.135509E 04
0.750295	0.744060E 05	0.167593E 03	0.135637E 04
0.760805	0.744702E 05	0.167743E 03	0.137022E 04
0.771099	0.745264E 05	0.168810E 03	0.137278E 04
0.781501	0.745543E 05	0.168838E 03	0.137397E 04
0.791602	0.746719E 05	0.168894E 03	0.137630E 04
0.802022	0.752792E 05	0.170693E 03	0.138759E 04
0.812150	0.753303E 05	0.170817E 03	0.139410E 04
0.822528	0.754507E 05	0.171034E 03	0.139939E 04
0.832605	0.755162E 05	0.171118E 03	0.140122E 04
0.842944	0.767012E 05	0.172212E 03	0.141640E 04
0.853373	0.767588E 05	0.172272E 03	0.142021E 04
0.863667	0.771173E 05	0.172608E 03	0.143139E 04
0.873880	0.776228E 05	0.173693E 03	0.145993E 04
0.883896	0.777778E 05	0.173823E 03	0.146507E 04
0.893908	0.778339E 05	0.173876E 03	0.146766E 04

The curves for weight, cost, and cube, figure 5, show a step type function where the constraint raises to consecutive plateau levels. This plateau effect is due in part to the grouped values associated with the spares and in part to the fact that for some of the items there were no cost, weights, or cubes available. The value of this figure, besides presenting a great many data points in a concise format, is its assistance in selecting the optimum choices for a given constraint. For example, if it were desired to get the best protection possible for the least cost, the graph shows that the 50% level which cost $73,000.00 is not the logical position to select. One would get more for his money by choosing the 80% level which costs a little over $75,000.00. By choosing the latter point over the former, the user has obtained an additional 30% protection at an additional cost of only $2,000.00.

CRITICAL PART STOCK LIST

Table A-2 shows the provisioning list determined for critical and ship installable parts, code 1 items, only. This list is in the same format as the equipment stock list previously presented as well as the criterion of selecting the parts for sparing on the basis of highest likelihood of requiring replacement. The list represents a provisioning level of 90% for the equipment's code 1 parts for a 90-day stock period. This list represents a range of 1,502 part types and a depth of 1,741 parts which have a total volume of 172 cubic feet, a total weight of 1,400 lbs., and a total cost of $75,087.00.

The provisioning level was initially defined as the probability that an equipment or system will not require more than the stated number of spare parts during a specified stock period. This general definition may

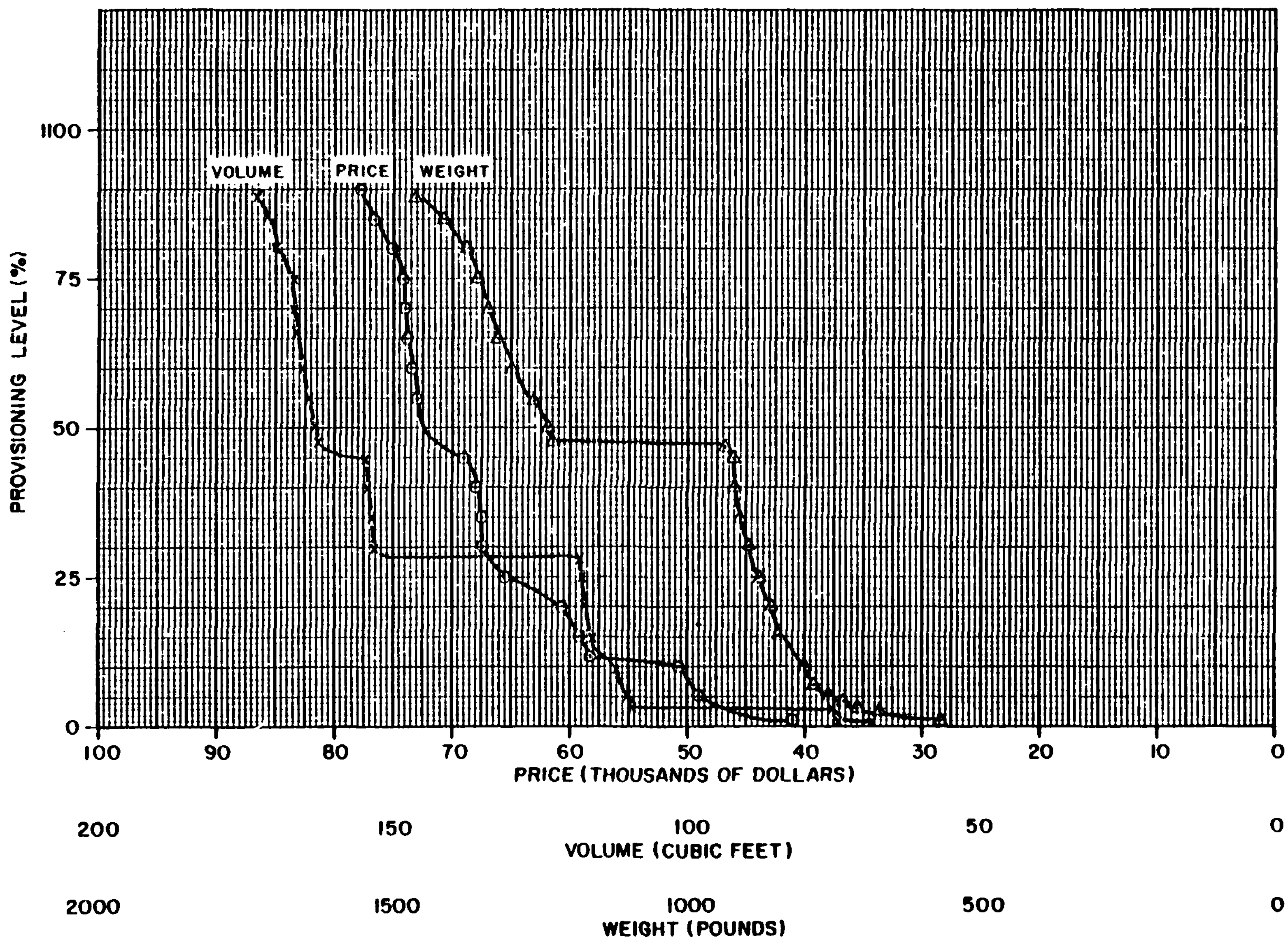


Figure 5. Equipment Stock Constraints Graph - Critical/Noncritical Parts

be applied to all cases; however, for the critical item only stock list of table A-2 an additional feature can be included. Since only critical items are included in the provisioning list and critical items are defined as those items essential to the operation of the unit in which they are located, the provisioning list of table A-2 is directly related to the ability to keep the equipment in operation. The other provisioning lists are indirectly related to keeping the equipment in operation because they include in their computations both critical and noncritical items. The definition of the 90% provisioning level of table A-2 can be restated as the probability that the equipment will not be down at the end of a 90-day stock period due to a lack of shipboard installable spare parts.

CRITICAL PART (MINIMUM DEPTH) STOCK LIST

The provisioning list of table A-3 contains at least one spare for every critical shipboard installable part type. The initial step in generating this provisioning list was to select a 90% provisioning level for the equipment and then computed for all shipboard installable parts, critical and noncritical, the spare part provisioning list. At this point the provisioning list was exactly the same as the provisioning list previously presented in table A-1. The next step was to select from the provisioning list all those critical part types which had not been allowed a spare. Each of these critical part types without spares was then arbitrarily assigned one spare part to form an adjusted provisioning list. The total spare part provisioning list was then reinserted in the computer and the provisioning level was calculated. The provisioning was found to be 93.9%. This list represents a range of 2,043 part types and a depth of 2,337 parts which have a total volume of 190 cubic feet, a total weight of 1,494 pounds, and a total cost of $79,190.00. The addition of one spare

for every part which had not been provided in table A-1 increased the provisioning level of table A-3 by 3.9% and also generated the following increases:

234	part types or range
234	parts in depth
15.6	volume in cubic feet
22.7	weight in pounds
$1,132.00	cost in dollars

The critical part types which did not have a spare in table A-1 and were arbitrarily assigned a spare part are presented in table A-4. As shown above, this table contains 234 critical part types.

EQUIPMENT STOCK LIST (PARTS AND ASSEMBLIES)

A stock list for the AN/SPS-40 is shown in table A-5 which is distinct from the three previously discussed stock lists in that this stock list provisions both parts and assemblies. The equipment stock lists of critical/noncritical parts, critical parts only, and critical parts (minimum depth) shown in tables A-1, A-2, and A-3 respectively, all assume that the Navy technician will perform all the code 1 and 3 repairs on the AN/SPS-40 Radar. Because of the assumption that the repairs will be made by the Navy technicians, only parts are shown in those stock lists.

The equipment parts and assemblies stock list of table A-5 considers the technician skill level, the availability of on-site test equipment, and Navy instructions and regulations which preclude the possibility of complete repairs by the Navy technician. The Electronics Maintenance Engineering Center furnished the data on the non-repairable assemblies. There were [illegible] assemblies to be repaired by the manufacturer which are as follows:

2A2	5A9	5A36	Unit 11
3A2	5A10	5A37	22A2
3A3	5A11	5A38	22A3
3A4	5A12	5A39	22A4
3A5	5A13	5A40	22A5
3A6	5A14	5A42	22A6
3A7	5A15	5A43	22A7
3A9	5A24	5A45	22A8
3Z3	5A25	5A46	22A9
4A2	5A26	5A48	23A2
4A3	5A27	5A49	23A3
4A4	5A28	5A50	23A4
4T2	5A29	5A55	23A6
5A3	5A30	5A56	23A7
5A4	5A31	5A57	24A1
5A5	5A32	5A58	24A2
5A6	5A33	6A3XV1	24A3
5A7	5A34	6A3XV2	24A4
5A8	5A35	6A4	24A5

Also included in the EMEC data were three units (units 10, 12, and 18) which were to be repaired by the shipyard and three additional assemblies (12A3A3, 12A3A3B1, and 12A3A4) which EMEC did not consider to be repairable by the technician.

In order to consider these conditions properly the input data cards were revised such that the parts within the yard repairable units were coded 2 and 4, the parts in the manufacturer's repairable assemblies were deleted except tubes, and data cards for each of the assemblies were added. A total parts count cannot be obtained by summing the items shown in column 9 of table A-5 because the deleted assembly parts are no longer in the stock system but are to be provided by the contractor's repair facility.

There were 84 assemblies listed as being non-repairable by Navy technicians. These assemblies would be returned to the manufacturer for repair with the exception that the Navy technician would be allowed to repair or replace malfunctioned plug-in parts in the assemblies. The great majority of the plug-in type parts are comprised of electron tubes.

This technician repair allowance was made because it was considered to be standard operating procedure as well as a realistic approach to the problem. Since the plug-in parts are to be replaced, these are the only parts within the non-repairable assemblies which were not deleted from the data card deck. It was necessary to delete the non-replaceable parts, otherwise, the computer would spare parts which are not required.

The procedure used in determining the parts and assemblies stock list was to calculate the spares required to reach the 90% provisioning level for a three-month stock period considering both critical and noncritical items, where items refers to both parts and assemblies. To this stock list was added one spare for each critical item that had not been provided a spare. The 223 critical items which were added to the 90% provisioning list are shown in table A-6. The provisioning level was recalculated and found to be 94.1%. The parts and assemblies stock list, table A-5, had a range of 1,442 items and a depth of 1,698 items allowed as spares of which 1,557 are parts and 141 are assemblies. The stock has a cost of $131,326.00, a volume of 155 cubic feet, and weighs 1,331 pounds.

The stock list shown in table A-5 is recommended for use for AN/SPS-40 Radar since present logistic philosophy and pertinent field conditions have been taken into consideration. In those cases where all repairs will be performed by the Navy technician, one of the three previous procedures would be suggested.

Equipment stock period variations for the parts and assemblies stock list have been tabulated in table 6. Figure 6 presents these data in graphical form.

TABLE 6. EQUIPMENT STOCK PERIOD VARIATIONS - PARTS AND ASSEMBLIES

Provisioning Level	Normalized Time (90 days = 1.00)
0.99799	0.08
0.99772	0.09
0.99744	0.10
0.99435	0.20
0.99068	0.30
0.98637	0.40
0.98133	0.50
0.97549	0.60
0.96872	0.70
0.96085	0.80
0.95168	0.90
0.94089	1.00
0.93851	1.02
0.93605	1.04
0.93350	1.06
0.93086	1.08
0.92812	1.10
0.92529	1.12
0.92235	1.14
0.91931	1.16
0.91615	1.18
0.91288	1.20
0.90417	1.25
0.89463	1.30
0.88418	1.35
0.87275	1.40
0.86027	1.45
0.84666	1.50
0.81583	1.60
0.73861	1.80
0.64099	2.00
0.40871	2.40
0.19780	2.80
0.06957	3.20
0.01739	3.60
0.00307	4.00

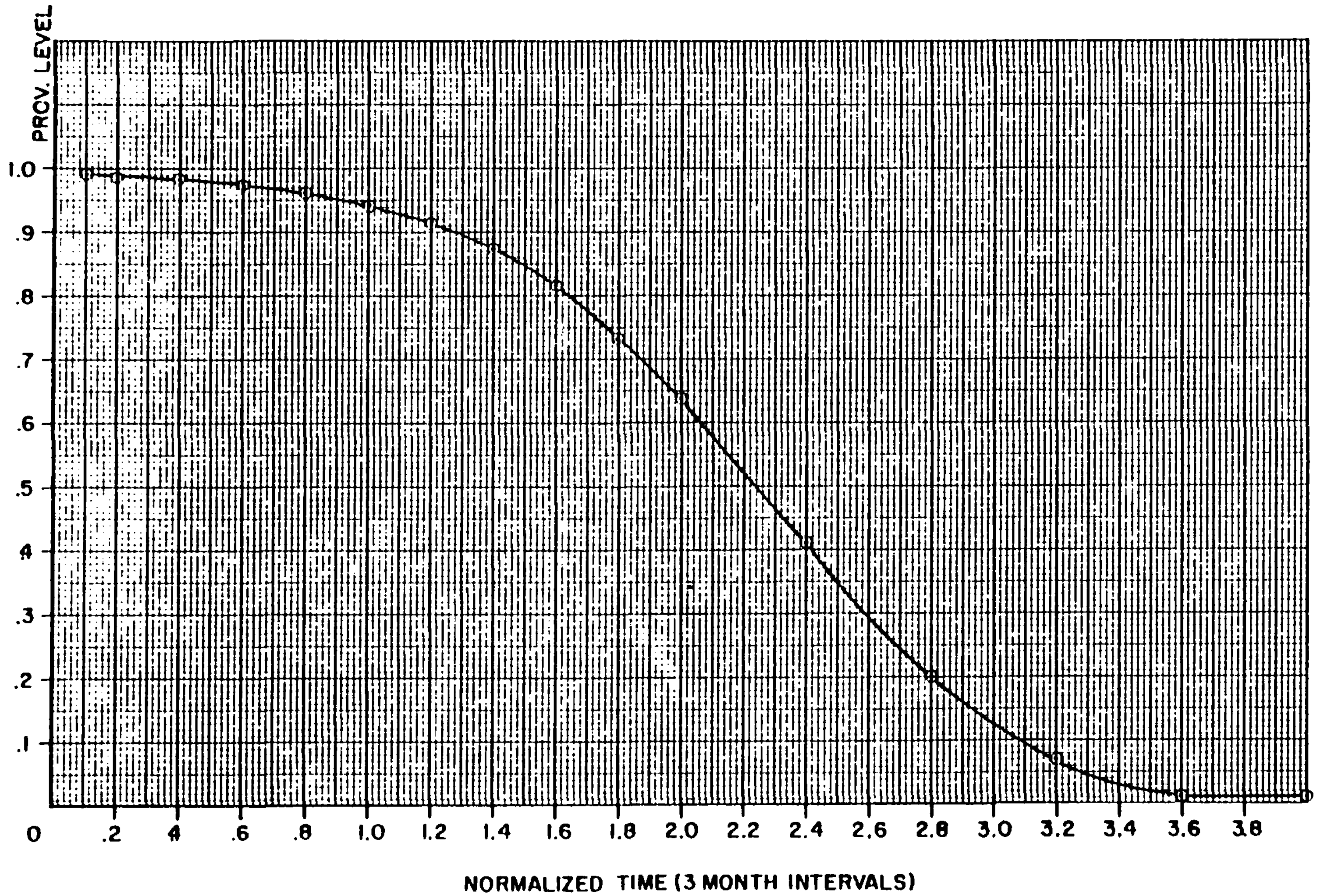


Figure 6. Equipment Stock Period Variation Graph - Parts and Assemblies

This information is used to determine provisioning levels associated with a range of stock periods. The constraints of cost, cube, and weight are shown in table 7 and figure 7 for the parts and assemblies stock list.

It should be noted at this point that the AN/SPS-40 has, according to the stock list for parts and assemblies, lost its repair capability for the 34 modules since no spare parts would be available. When considering a ship as a whole, however, it is still likely that some repairs could be made due to the large range of parts allowed by a COSAL.

EMEC ADJUSTED LIST

The above stock list for parts and assemblies shown on table A-5 was adjusted by EMEC in accordance with their experience on the AN/SPS-40 Radar. In some cases it was determined that the items were being replaced at a lower rate than originally assigned to the item. In these cases the stock quantities were reduced. It was also EMEC's desire to reduce the $131,326.00 cost of table A-5 stock list. Certain parts were selected for stocking rather than expensive assemblies. The resultant EMEC adjusted stock quantities were calculated to have a 92.9% provisioning level, a range of 1,458 part types, a depth of 1,706 parts, a cost of $100,212.00, a volume of 121 cubic feet, and a weight of 711 pounds.

SUPPORT SHIP STOCK LIST

The load list for the support ship for the AN/SPS-40 for parts only is shown in table 7. The support ship's list is calculated at the 95% provisioning level for a six-month stock period for six equipments per support ship. If the support ship stocks the recommended load, then all equipments when in the company of the support ship will be protected with an overall 95% provisioning level. This means that the support ship carries enough additional parts over that carried for the equipment to raise the

TABLE 7. EQUIPMENT STOCK CONSTRAINTS - PARTS AND ASSEMBLIES

Provisioning Level	Price	Cube	Weight
0.000000	0.460000E 01	0.219000E-02	0.600000E-01
0.010020	0.564986E 05	0.512922E 02	0.442510E 03
0.020163	0.630694E 05	0.553097E 02	0.496180E 03
0.030260	0.655961E 05	0.569700E 02	0.510790E 03
0.040276	0.734214E 05	0.625319E 02	0.535119E 03
0.050582	0.767441E 05	0.664619E 02	0.550049E 03
0.060601	0.786909E 05	0.687786E 02	0.634629E 03
0.070666	0.790194E 05	0.691151E 02	0.648359E 03
0.081159	0.797319E 05	0.694002E 02	0.656119E 03
0.091374	0.805878E 05	0.700450E 02	0.666565E 03
0.101768	0.815539E 05	0.103910E 03	0.696165E 03
0.112371	0.844762E 05	0.105138E 03	0.702615E 03
0.122517	0.854417E 05	0.105687E 03	0.713365E 03
0.132609	0.857507E 05	0.105865E 03	0.722125E 03
0.143064	0.864888E 05	0.106742E 03	0.728675E 03
0.153677	0.865015E 05	0.106824E 03	0.731985E 03
0.164015	0.871172E 05	0.107476E 03	0.733175E 03
0.174195	0.871343E 05	0.107496E 03	0.733955E 03
0.184847	0.876317E 05	0.107992E 03	0.743115E 03
0.195490	0.877406E 05	0.108566E 03	0.748165E 03
0.206259	0.952495E 05	0.111938E 03	0.749075E 03
0.216630	0.955943E 05	0.112280E 03	0.758125E 03
0.226787	0.956654E 05	0.112338E 03	0.762075E 03
0.236843	0.957498E 05	0.112418E 03	0.767845E 03
0.247255	0.960673E 05	0.112666E 03	0.778244E 03
0.257719	0.961858E 05	0.112714E 03	0.780454E 03
0.268345	0.961951E 05	0.112741E 03	0.781384E 03
0.278470	0.962186E 05	0.112820E 03	0.783464E 03
0.288977	0.962261E 05	0.112865E 03	0.784334E 03
0.299752	0.980972E 05	0.113326E 03	0.785434E 03
0.310503	0.989764E 05	0.113566E 03	0.787294E 03
0.321240	0.995741E 05	0.117740E 03	0.788654E 03
0.331475	0.104606E 06	0.117973E 03	0.798704E 03
0.342366	0.104658E 06	0.117992E 03	0.800074E 03
0.353158	0.104658E 06	0.117995E 03	0.801424E 03
0.363997	0.104742E 06	0.118027E 03	0.802574E 03
0.374765	0.105137E 06	0.118233E 03	0.808004E 03
0.385742	0.105261E 06	0.118333E 03	0.813174E 03
0.395972	0.105481E 06	0.118408E 03	0.815374E 03
0.406872	0.107618E 06	0.120029E 03	0.818554E 03
0.417403	0.109423E 06	0.120489E 03	0.820874E 03
0.428186	0.108436E 06	0.120500E 03	0.821364E 03
0.438230	0.108445E 06	0.120514E 03	0.821994E 03
0.448511	0.108458E 06	0.120527E 03	0.822564E 03
0.459032	0.108500E 06	0.120577E 03	0.823814E 03

TABLE 7. EQUIPMENT STOCK CONSTRAINTS - PARTS AND ASSEMBLIES (Continued)

Provisioning Level	Price	Cube	Weight
0.469771	0.108710E 06	0.120787E 03	0.824104E 03
0.480428	0.108828E 06	0.120869E 03	0.826624E 03
0.491268	0.108857E 06	0.120918E 03	0.829674E 03
0.502134	0.108865E 06	0.120972E 03	0.832790E 03
0.513239	0.109044E 06	0.121009E 03	0.836020E 03
0.523444	0.109044E 06	0.121009E 03	0.836020E 03
0.533852	0.109045E 06	0.121013E 03	0.836140E 03
0.544686	0.110685E 06	0.121699E 03	0.837320E 03
0.555443	0.110969E 06	0.121729E 03	0.838500E 03
0.565993	0.110970E 06	0.121732E 03	0.839700E 03
0.576744	0.110971E 06	0.121736E 03	0.840900E 03
0.587699	0.110972E 06	0.121742E 03	0.841770E 03
0.597711	0.114472E 06	0.130314E 03	0.114279E 04
0.608284	0.115286E 06	0.130858E 03	0.114371E 04
0.618858	0.115316E 06	0.130874E 03	0.114416E 04
0.629647	0.115476E 06	0.131212E 03	0.114861E 04
0.639730	0.115860E 06	0.131604E 03	0.114945E 04
0.649785	0.116401E 06	0.131858E 03	0.115096E 04
0.660683	0.116570E 06	0.132056E 03	0.115588E 04
0.671167	0.116759E 06	0.132145E 03	0.116082E 04
0.681444	0.117271E 06	0.132555E 03	0.116229E 04
0.692237	0.117299E 06	0.132713E 03	0.117099E 04
0.702279	0.117442E 06	0.133899E 03	0.120739E 04
0.712861	0.117467E 06	0.134098E 03	0.121310E 04
0.723384	0.117567E 06	0.134236E 03	0.121656E 04
0.733983	0.117647E 06	0.134576E 03	0.121827E 04
0.744711	0.117780E 06	0.134705E 03	0.122150E 04
0.754814	0.117888E 06	0.140428E 03	0.122351E 04
0.765005	0.117964E 06	0.140927E 03	0.123116E 04
0.775152	0.117966E 06	0.140935E 03	0.123284E 04
0.785434	0.117967E 06	0.140938E 03	0.123458E 04
0.795853	0.117992E 06	0.140956E 03	0.123542E 04
0.806410	0.117993E 06	0.140959E 03	0.123710E 04
0.816903	0.118407E 06	0.141119E 03	0.123850E 04
0.827352	0.120387E 06	0.143630E 03	0.125231E 04
0.837767	0.120426E 06	0.143764E 03	0.125469E 04
0.848006	0.120542E 06	0.143764E 03	0.125688E 04
0.858067	0.121121E 06	0.145559E 03	0.126805E 04
0.868372	0.121480E 06	0.145973E 03	0.127375E 04
0.878764	0.122859E 06	0.147291E 03	0.127911E 04
0.888986	0.124063E 06	0.148423E 03	0.129363E 04
0.899091	0.130545E 06	0.153911E 03	0.131050E 04

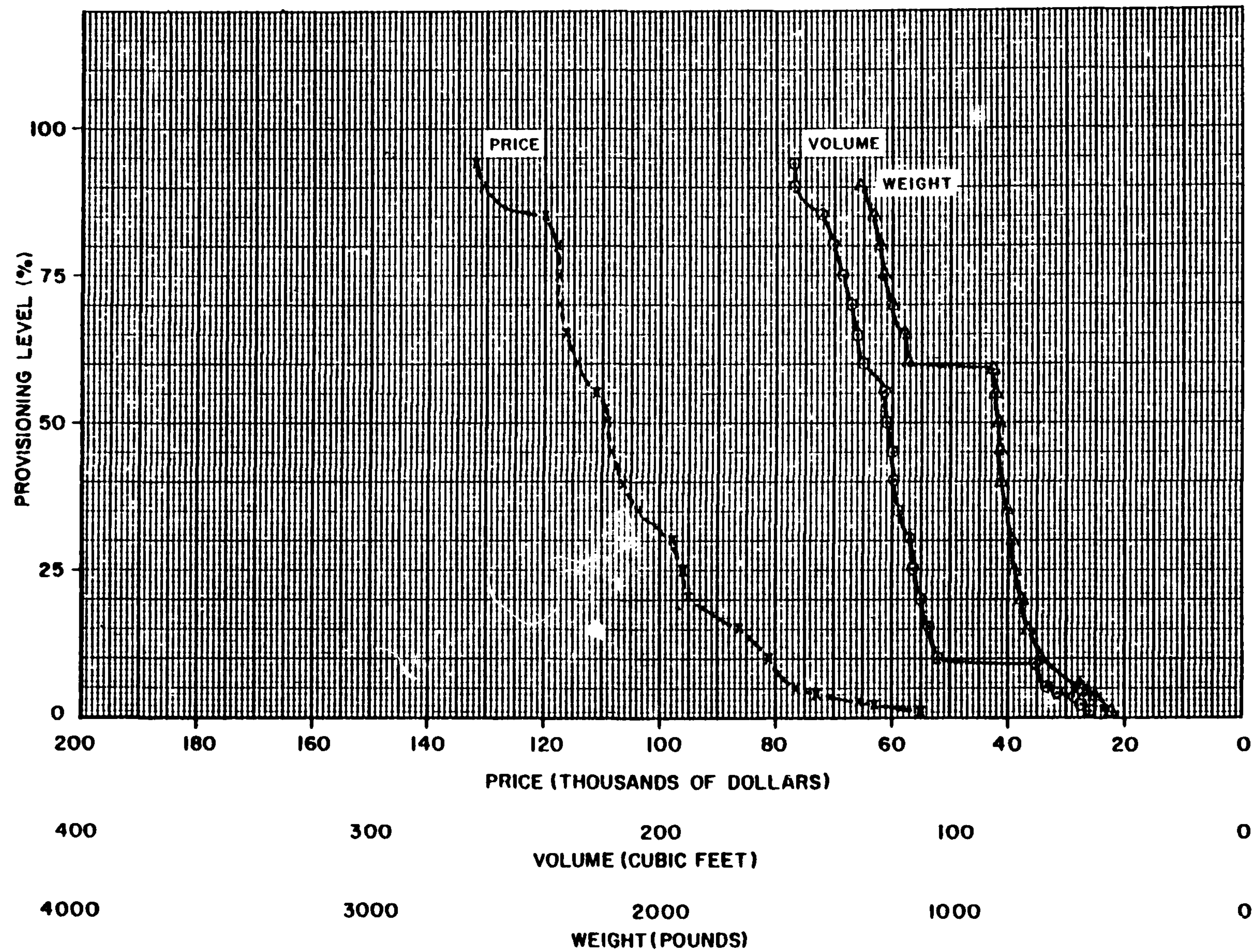


Figure 7. Equipment Stock Constraints Graph - Parts and Assemblies

provisioning level to a combined level of 95%. The individual ship level would therefore be much higher than 95%. It is important to note that this modeling procedure uses the support ship for emergency back-up only, and is not, therefore, expected to furnish normal usage to the equipment. If supply of normal usage were expected of the support ship, its load would have to be increased above that stated in table A-7. The equipments are to draw their normal usage from the depot.

Columns 1 through 7 of table A-7 carry the same description as previously given for the equipment's stock list. Column 8 shows the normalized replacement rate which is the part type replacement rate per 180 days times six, where six represents the number of equipments per support ship. Column 9 contains the number of applications of the part type per equipment within the code class of column 3 thereby giving the same values as presented for the equipment's provisioning list. Column 10 lists the number of each part type to be carried aboard the support ship. The summation of column 10 is the total number of items carried by the support ship to support the AN/SPS-40 under the above described conditions.

The support ship stock list for parts recommends a range of 2,133 different part types and a depth of 2,264 parts which have a total price of $72,729.00, a total volume of 173 cubic feet, and a total weight of 1,141 pounds.

Table A-8 shows the recommended support ship stock list for parts and assemblies which has a range of 581 different type items, a total depth of 902 items, a total price of $120,768.00, a total volume of 124 cubic feet, and a total weight of 917 pounds. The format of table A-8 is the same as that described above for table A-7.

SUPPORT SHIP STOCK PERIOD VARIATION

Support ship stock period variation for provisioning parts only is shown in table 8. The two columns shown in table 8 which are the provisioning level and the normalized time are the same type of information as presented in the equipment stock period variation section except that the time has been normalized on the basis of six months. The 0.1 increment of time therefore indicates a period of approximately 18 days in the case of the support ship listing. The results of these data are shown graphically in figure 8.

SUPPORT SHIP STOCK CONSTRAINTS

The support ship constraints for parts only, table 9, is in the same format as ship constraints where the necessity of adjustment of the support ship load may be determined on the basis of price, cube, or weight. Figure 9 shows the constraint of price, cube, and weight plotted as a function of provisioning level. Table 10 and figure 10 show the constraints of price, cube, and weight as they apply to a support ship which is stocking a combination of parts and assemblies.

DEPOT STOCK LISTS

The two depot stock lists have been computed at the 99% level for a six-month period for 42 AN/SPS-40 Radars. The first depot stock list for parts only is shown in table A-9 and the second depot stock list for parts and assemblies is shown in table A-10 where again columns 1 through 7 and column 9 are the same as in previously described stock lists. The normalized replacement rate, column 8, is the part type replacement rate per 180 days times 42 where 42 represents the number of equipments per depot. Column 12 lists the spares recommended for the depot. This total is represented by

TABLE 8. SUPPORT SHIP STOCK PERIOD VARIATION - PARTS ONLY

Provisioning Level	Normalized Time (180 days = 1.00)
0.99997	0.08
0.99996	0.09
0.99994	0.10
0.99966	0.20
0.99891	0.30
0.99745	0.40
0.99501	0.50
0.99125	0.60
0.98577	0.70
0.97800	0.80
0.96691	0.90
0.95017	1.00
0.94569	1.02
0.94067	1.04
0.93497	1.06
0.92847	1.08
0.92098	1.10
0.91231	1.12
0.90223	1.14
0.89045	1.16
0.87668	1.18
0.86061	1.20
0.80813	1.25
0.73482	1.30
0.63875	1.35
0.52334	1.40
0.39820	1.45
0.27724	1.50
0.09753	1.60
0.00247	1.80

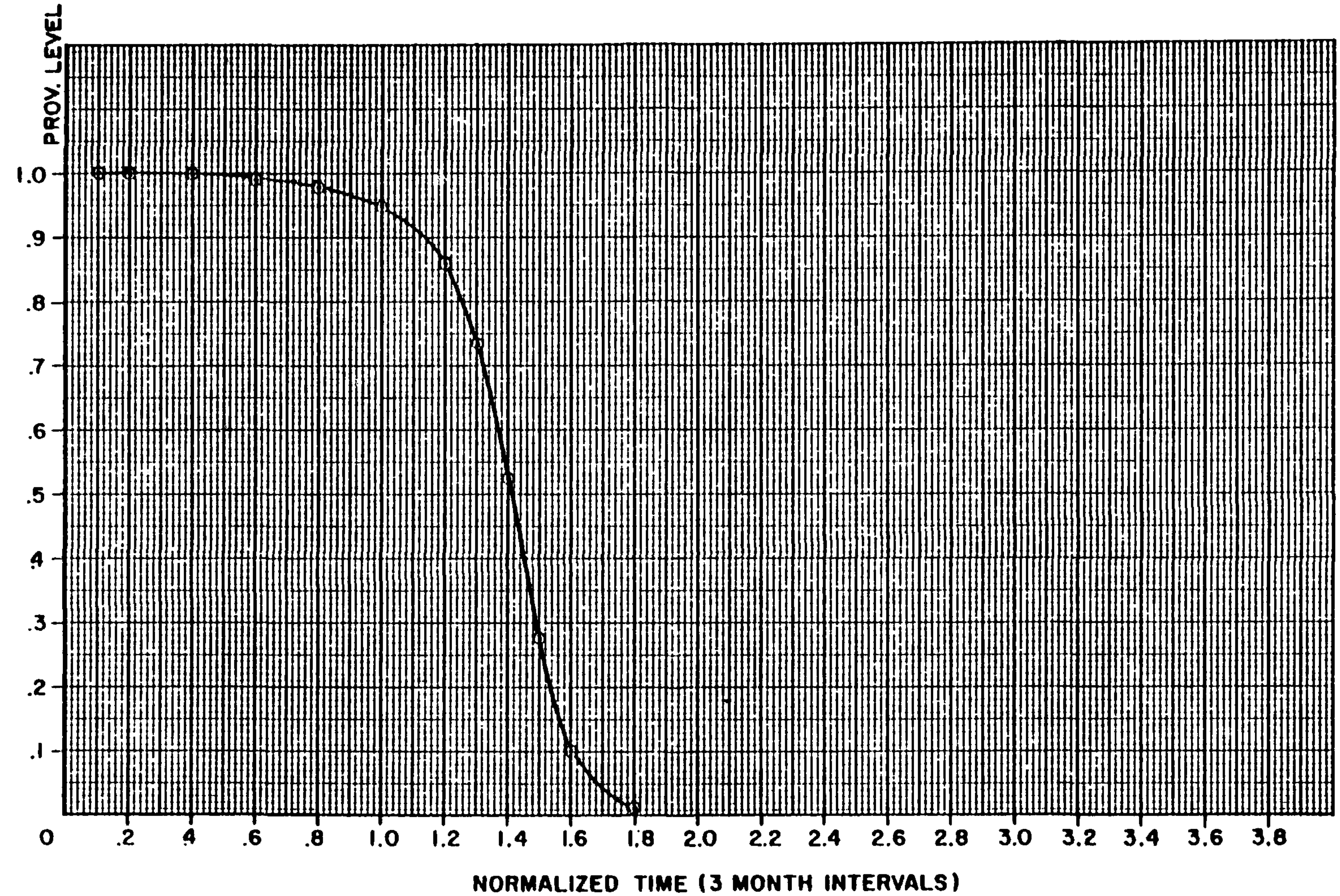


Figure 8. Support Ship Stock Period Variation Graph - Parts Only

TABLE 9. SUPPORT SHIP STOCK CONSTRAINTS - PARTS ONLY

Provisioning Level	Price	Cube	Weight
0.010102	0.460978E 05	0.110971E 03	0.967768E 03
0.020351	0.463034E 05	0.111654E 03	0.976638E 03
0.030380	0.[illegible]404E 05	0.111862E 03	0.983078E 03
0.040767	0.465436E 05	0.111874E 03	0.986328E 03
0.051104	0.465542E 05	0.111893E 03	0.988648E 03
0.061232	0.465840E 05	0.111901E 03	0.990148E 03
0.071728	0.465850E 05	0.111904E 03	0.991828E 03
0.082004	0.466088E 05	0.111918E 03	0.992968E 03
0.092056	0.466712E 05	0.112040E 03	0.100611E 04
0.102556	0.466844E 05	0.112076E 03	0.100720E 04
0.112566	0.467113E 05	0.112093E 03	0.100772E 04
0.122861	0.467230E 05	0.112101E 03	0.100828E 04
0.133044	0.468677E 05	0.112160E 03	0.101008E 04
0.143958	0.468717E 05	0.112185E 03	0.101084E 04
0.154519	0.468779E 05	0.112191E 03	0.101148E 04
0.165472	0.469135E 05	0.112293E 03	0.101617E 04
0.175505	0.469202E 05	0.112309E 03	0.101738E 04
0.186147	0.469207E 05	0.112311E 03	0.101750E 04
0.197226	0.470282E 05	0.112502E 03	0.102220E 04
0.207270	0.470463E 05	0.112540E 03	0.102321E 04
0.217447	0.470521E 05	0.112553E 03	0.102351E 04
0.228796	0.470761E 05	0.112562E 03	0.102421E 04
0.238860	0.470859E 05	0.112576E 03	0.102522E 04
0.249367	0.470962E 05	0.112582E 03	0.102564E 04
0.260336	0.471094E 05	0.112594E 03	0.102647E 04
0.271787	0.471301E 05	0.112618E 03	0.102822E 04
0.282002	0.471479E 05	0.112638E 03	0.102921E 04
0.292601	0.471658E 05	0.112658E 03	0.103023E 04
0.303336	0.471966E 05	0.112709E 03	0.103219E 04
0.314704	0.472638E 05	0.112748E 03	0.103316E 04
0.324787	0.472832E 05	0.112782E 03	0.103390E 04
0.335193	0.472876E 05	0.112791E 03	0.103414E 04
0.345932	0.474017E 05	0.112952E 03	0.104097E 04
0.356715	0.475479E 05	0.113432E 03	0.105404E 04
0.366984	0.475662E 05	0.113467E 03	0.105475E 04
0.377549	0.475692E 05	0.113473E 03	0.105499E 04
0.388296	0.475808E 05	0.113500E 03	0.105564E 04
0.398887	0.475861E 05	0.113504E 03	0.105585E 04
0.409670	0.475925E 05	0.113514E 03	0.105649E 04
0.420468	0.475925E 05	0.113514E 03	0.105649E 04
0.430695	0.475969E 05	0.113590E 03	0.105882E 04
0.440990	0.476187E 05	0.113634E 03	0.106051E 04
0.451523	0.476362E 05	0.113653E 03	0.106151E 04
0.461945	0.476392E 05	0.113656E 03	0.106179E 04
0.472237	0.476602E 05	0.128667E 03	0.106593E 04
0.482758	0.477614E 05	0.128710E 03	0.106664E 04
0.493514	0.477614E 05	0.128710E 03	0.106664E 04
0.504509	0.477614E 05	0.128710E 03	0.106664E 04

TABLE 8. SUPPORT SHIP STOCK CONSTRAINTS - PARTS ONLY (Continued)

Provisioning Level	Price	Cube	Weight
0.515749	0.477614E 05	0.128710E 03	0.106664E 04
0.527239	0.478336E 05	0.129019E 03	0.107393E 04
0.535958	0.478535E 05	0.129197E 03	0.107754E 04
0.550994	0.478544E 05	0.129200E 03	0.107772E 04
0.561205	0.478544E 05	0.129200E 03	0.107772E 04
0.571306	0.479374E 05	0.129217E 03	0.107885E 04
0.581513	0.479907E 05	0.129227E 03	0.107958E 04
0.591902	0.481605E 05	0.129232E 03	0.108022E 04
0.602476	0.482895E 05	0.129255E 03	0.108091E 04
0.612758	0.482924E 05	0.129259E 03	0.108109E 04
0.622857	0.483090E 05	0.129268E 03	0.108152E 04
0.634802	0.483456E 05	0.129310E 03	0.108391E 04
0.644875	0.483456E 05	0.129310E 03	0.108391E 04
0.655969	0.483700E 05	0.129351E 03	0.108555E 04
0.666381	0.484273E 05	0.129365E 03	0.108620E 04
0.676958	0.484815E 05	0.129383E 03	0.108700E 04
0.687702	0.484815E 05	0.129383E 03	0.108700E 04
0.698617	0.484943E 05	0.129413E 03	0.108777E 04
0.709334	0.486082E 05	0.129508E 03	0.108870E 04
0.719460	0.486145E 05	0.129553E 03	0.108946E 04
0.729730	0.486339E 05	0.129584E 03	0.109011E 04
0.740148	0.486379E 05	0.129596E 03	0.109053E 04
0.750713	0.486601E 05	0.129618E 03	0.109098E 04
0.761191	0.486767E 05	0.129641E 03	0.109156E 04
0.772342	0.486878E 05	0.129671E 03	0.109265E 04
0.783062	0.486968E 05	0.129688E 03	0.109311E 04
0.793930	0.486976E 05	0.129704E 03	0.109330E 04
0.804948	0.487358E 05	0.129807E 03	0.109542E 04
0.816120	0.487893E 05	0.129876E 03	0.109885E 04
0.827447	0.487893E 05	0.129876E 03	0.109885E 04
0.837534	0.560585E 05	0.132988E 03	0.109965E 04
0.848335	0.560878E 05	0.133033E 03	0.110073E 04
0.859180	0.561204E 05	0.133057E 03	0.110208E 04
0.869803	0.563258E 05	0.133092E 03	0.110316E 04
0.879894	0.568646E 05	0.133104E 03	0.110342E 04
0.890358	0.568646E 05	0.133104E 03	0.110342E 04
0.900945	0.568646E 05	0.133104E 03	0.110342E 04
0.911659	0.568646E 05	0.133104E 03	0.110342E 04
0.921920	0.690424E 05	0.136302E 03	0.110926E 04
0.932161	0.692641E 05	0.136417E 03	0.111805E 04
0.942377	0.713378E 05	0.171668E 03	0.112257E 04

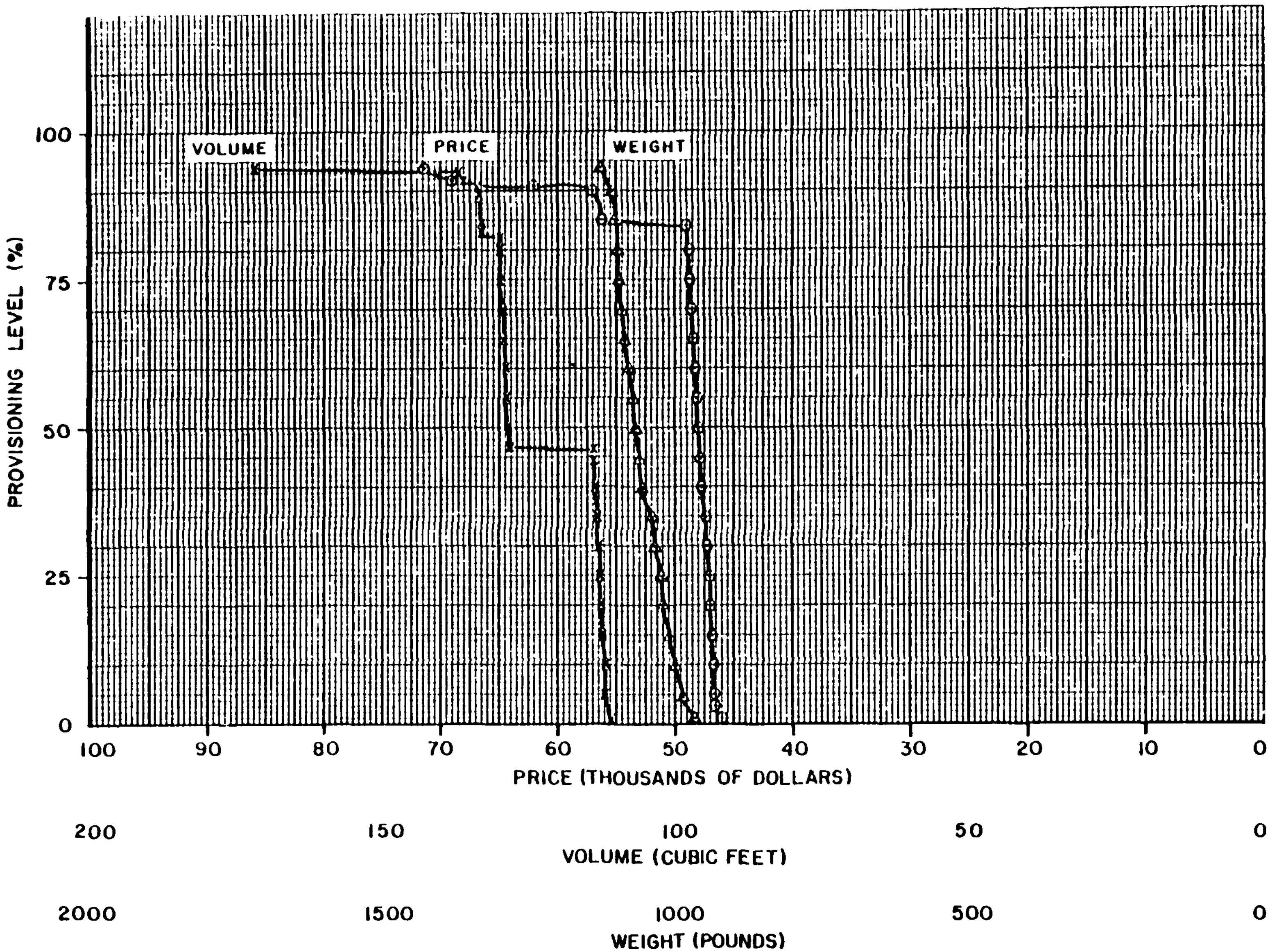


Figure 9. Support Ship Stock Constraints Graph - Parts Only

TABLE 10. SUPPORT SHIP STOCK CONSTRAINTS - PARTS AND ASSEMBLIES

Provisioning Level	Price	Cube	Weight
0.491605	0.494000E 01	0.179000E-01	0.420000E-00
0.502328	0.494660E 03	0.367790E-00	0.366000E 01
0.513914	0.633630E 03	0.492390E-00	0.390000E 01
0.525922	0.655740E 03	0.499710E-00	0.445000E 01
0.536894	0.199864E 04	0.954930E 00	0.499000E 01
0.548284	0.200544E 04	0.974160E 00	0.575000E 01
0.558470	0.233829E 04	0.137782E 01	0.662000E 01
0.569565	0.236429E 04	0.140996E 01	0.837000E 01
0.580880	0.237179E 04	0.141552E 01	0.862000E 01
0.591548	0.995586E 04	0.451133E 01	0.996000E 01
0.602511	0.100349E 05	0.496411E 01	0.202500E 02
0.613676	0.100461E 05	0.499240E 01	0.204900E 02
0.625049	0.100461E 05	0.499240E 01	0.204900E 02
0.635637	0.100905E 05	0.501004E 01	0.214700E 02
0.646593	0.109061E 05	0.537158E 01	0.215000E 02
0.657717	0.114563E 05	0.566668E 01	0.238400E 02
0.668850	0.123049E 05	0.596808E 01	0.500200E 02
0.679692	0.149074E 05	0.698605E 01	0.508700E 02
0.690538	0.152486E 05	0.716964E 01	0.530400E 02
0.701495	0.159007E 05	0.775249E 01	0.795100E 02
0.711639	0.166155E 05	0.810729E 01	0.812000E 02
0.722938	0.166742E 05	0.821393E 01	0.852500E 02
0.732972	0.166742E 05	0.821393E 01	0.852500E 02
0.743956	0.186075E 05	0.117478E 02	0.946600E 02
0.754506	0.270035E 05	0.161397E 02	0.998200E 02
0.764718	0.284058E 05	0.167031E 02	0.110910E 03
0.775010	0.287409E 05	0.193178E 02	0.126160E 03
0.785315	0.316970E 05	0.209793E 02	0.137290E 03
0.795462	0.374656E 05	0.219272E 02	0.166690E 03
0.805888	0.434714E 05	0.265664E 02	0.176020E 03
0.815947	0.450479E 05	0.276116E 02	0.194620E 03
0.826128	0.463310E 05	0.284075E 02	0.213130E 03
0.836424	0.481395E 05	0.298969E 02	0.222430E 03
0.846625	0.493468E 05	0.305927E 02	0.226460E 03
0.857034	0.555234E 05	0.313656E 02	0.252600E 03
0.867061	0.666656E 05	0.357610E 02	0.261120E 03
0.877097	0.728977E 05	0.455250E 02	0.587719E 03
0.887100	0.816603E 05	0.527813E 02	0.614669E 03
0.897236	0.850733E 05	0.583854E 02	0.681909E 03
0.907276	0.877951E 05	0.618097E 02	0.738259E 03
0.917485	0.917609E 05	0.649510E 02	0.757369E 03
0.927656	0.970415E 05	0.102173E 03	0.801835E 03
0.937748	0.107181E 06	0.116860E 03	0.867075E 03
0.947786	0.119030E 06	0.123297E 03	0.914184E 03

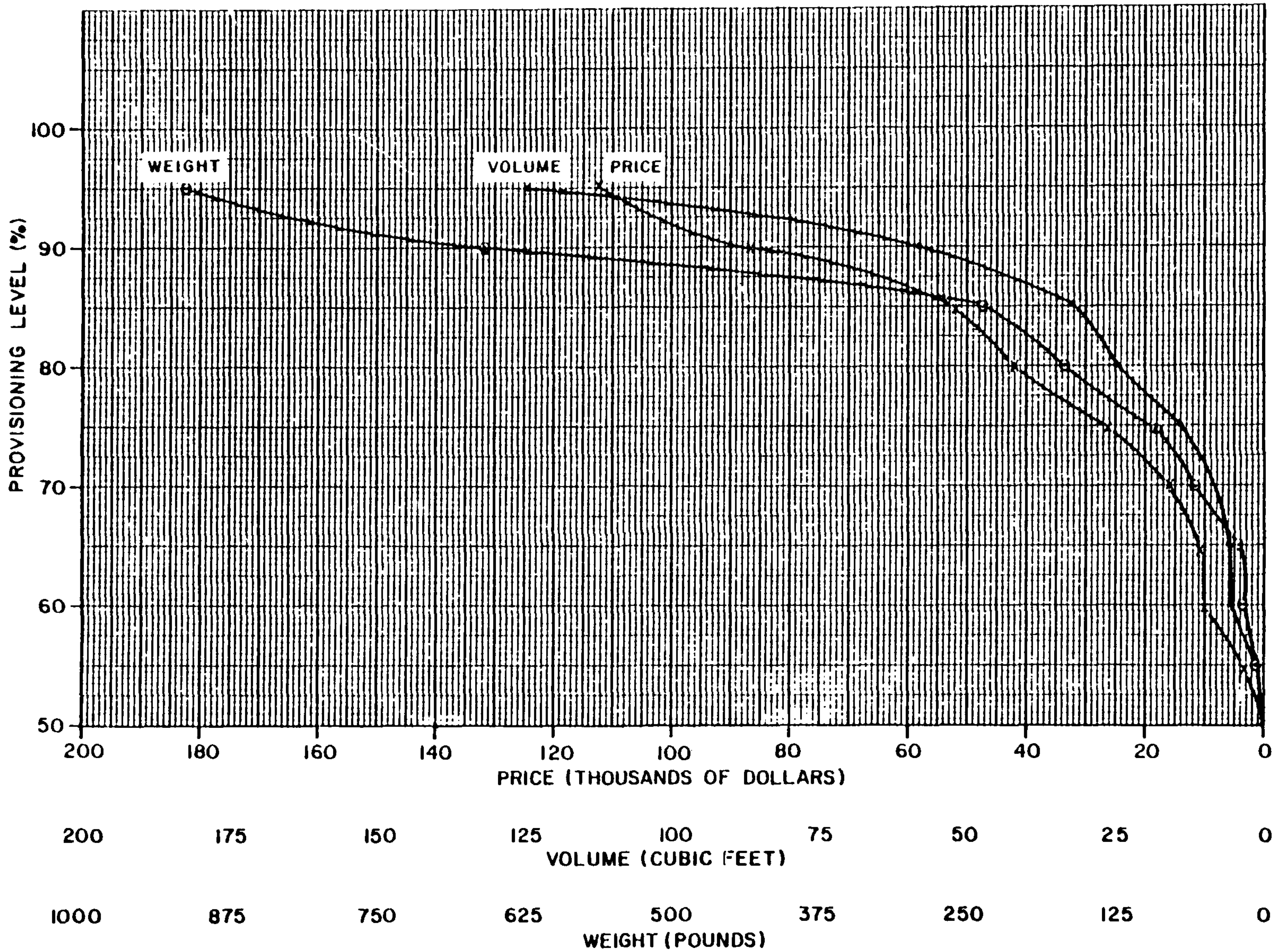


Figure 10. Support Ship Stock Constraints Graph - Parts and Assemblies

two sub-totals shown in columns 10 and 11. The number shown in column 11 represents the expected or normal usage for a three-month period. These normal usage items are expected to be issued by the depot each three-month period. The quantities listed in column 10 are back-up items required to raise the provisioning level of all equipments to 99% or only one time out of a hundred will the depot be unable to supply the requested part for all equipments. The depot stock list for parts only recommends a range of 2,178 part types and a depth of 5,259 parts which have a total volume of 677 cubic feet, a total weight of 4,304 pounds, and a total cost of $250,098.00. The depot stock lists for parts and assemblies recommends a range of 1,305 different type items and a total depth of 4,551 items which have a total volume of 642 cubic feet, a total weight of 4,451 pounds, and a total cost of $569,024.00. As stated in Section III, the program has the ability to consider lead time for depot stock quantity, but since these data were not available for the program, all lead times have been set at zero. The equipment and support ship were provisioned only with code 1 and 3 type parts since these were the only parts installable by the ship's force. The depot, however, stocks code 1, 2, 3, and 4 items since it must supply all the needs of the equipments.

DEPOT STOCK CONSTRAINTS

Tables 11 and 12, Stock Constraints, are in the same format as presented previously for equipment and support ship constraints where column 1 is the provisioning level, column 2 is the price, column 3 is the cube, and column 4 is the weight. Table 11 shows the depot constraints for provisioning parts only, and table 12 shows the depot constraints for provisioning parts and assemblies. Figure 11 shows price, cube, and weight

TABLE 11. DEPOT STOCK CONSTRAINTS - PARTS ONLY

Provisioning Level	Price		Cube		Weight	
0.010182	0.606914E	05	0.160034E	03	0.110422E	04
0.020330	0.607435E	05	0.160474E	03	0.111703E	04
0.031073	0.609205E	05	0.160520E	03	0.112399E	04
0.041540	0.611934E	05	0.160550E	03	0.112499E	04
0.052010	0.612407E	05	0.160598E	03	0.112756E	04
0.063062	0.612437E	05	0.160627E	03	0.112806E	04
0.074397	0.613740E	05	0.160686E	03	0.113071E	04
0.084621	0.613782E	05	0.160695E	03	0.113101E	04
0.096250	0.613862E	05	0.160706E	03	0.113129E	04
0.107482	0.613965E	05	0.160740E	03	0.113203E	04
0.119363	0.615089E	05	0.160833E	03	0.113313E	04
0.129664	0.615123E	05	0.160863E	03	0.113352E	04
0.140855	0.615332E	05	0.160893E	03	0.113428E	04
0.153011	0.615373E	05	0.160918E	03	0.113482E	04
0.163486	0.615387E	05	0.160923E	03	0.113496E	04
0.174679	0.615503E	05	0.160931E	03	0.113526E	04
0.186511	0.615626E	05	0.160955E	03	0.113561E	04
0.198841	0.615761E	05	0.160962E	03	0.113585E	04
0.211548	0.615761E	05	0.160962E	03	0.113585E	04
0.223845	0.615822E	05	0.160982E	03	0.113641E	04
0.236545	0.615986E	05	0.161008E	03	0.113734E	04
0.249966	0.616012E	05	0.161009E	03	0.113746E	04
0.260529	0.616012E	05	0.161009E	03	0.113746E	04
0.271539	0.616012E	05	0.161009E	03	0.113746E	04
0.283014	0.616011E	05	0.161036E	03	0.113815E	04
0.294973	0.616350E	05	0.161091E	03	0.113915E	04
0.307438	0.616402E	05	0.161129E	03	0.113977E	04
0.320430	0.616537E	05	0.161148E	03	0.114020E	04
0.333971	0.616937E	05	0.161197E	03	0.114320E	04
0.348084	0.616937E	05	0.161197E	03	0.114320E	04
0.362793	0.616937E	05	0.161197E	03	0.114320E	04
0.372943	0.616937E	05	0.161197E	03	0.114320E	04
0.383305	0.616946E	05	0.161213E	03	0.114339E	04
0.395760	0.641053E	05	0.167220E	03	0.114416E	04
0.409536	0.641148E	05	0.167250E	03	0.114453E	04
0.423791	0.641177E	05	0.167288E	03	0.114521E	04
0.438219	0.641280E	05	0.167299E	03	0.114579E	04
0.452973	0.641443E	05	0.167303E	03	0.114593E	04
0.463083	0.641443E	05	0.167303E	03	0.114593E	04
0.477091	0.641499E	05	0.167306E	03	0.114617E	04
0.490440	0.641749E	05	0.167316E	03	0.114666E	04
0.504161	0.643184E	05	0.167338E	03	0.114709E	04
0.517816	0.643904E	05	0.167353E	03	0.115049E	04
0.528569	0.644414E	05	0.167462E	03	0.115327E	04
0.540441	0.645938E	05	0.167504E	03	0.115538E	04
0.552504	0.645952E	05	0.167508E	03	0.115570E	04
0.564836	0.645952E	05	0.167508E	03	0.115570E	04
0.577444	0.645952E	05	0.167508E	03	0.115570E	04

TABLE 11. DEPOT STOCK CONSTRAINTS - PARTS ONLY (Continued)

Provisioning Level	Price	Cube	Weight
0.590333	0.645952E 05	0.167508E 03	0.115570E 04
0.603509	0.645952E 05	0.167508E 03	0.115570E 04
0.613584	0.645952E 05	0.167508E 03	0.115570E 04
0.623828	0.645952E 05	0.167508E 03	0.115570E 04
0.634242	0.645952E 05	0.167508E 03	0.115570E 04
0.644830	0.645952E 05	0.167508E 03	0.115570E 04
0.655595	0.645952E 05	0.167508E 03	0.115570E 04
0.666539	0.645952E 05	0.167508E 03	0.115570E 04
0.677667	0.645952E 05	0.167508E 03	0.115570E 04
0.688980	0.645952E 05	0.167508E 03	0.115570E 04
0.700482	0.645952E 05	0.167508E 03	0.115570E 04
0.712175	0.645952E 05	0.167508E 03	0.115570E 04
0.724065	0.645952E 05	0.167508E 03	0.115570E 04
0.736152	0.645952E 05	0.167508E 03	0.115570E 04
0.748442	0.645952E 05	0.167508E 03	0.115570E 04
0.760936	0.645952E 05	0.167508E 03	0.115570E 04
0.763331	0.645998E 05	0.167512E 03	0.115588E 04
0.786107	0.646087E 05	0.167526E 03	0.115615E 04
0.796214	0.670140E 05	0.173533E 03	0.115729E 04
0.806533	0.670142E 05	0.173537E 03	0.115755E 04
0.816602	0.676064E 05	0.173994E 03	0.116924E 04
0.826763	0.679627E 05	0.174242E 03	0.118267E 04
0.836886	0.688897E 05	0.174375E 03	0.118677E 04
0.846920	0.693640E 05	0.174877E 03	0.119455E 04
0.857135	0.799787E 05	0.184328E 03	0.120718E 04
0.867416	0.808355E 05	0.184595E 03	0.124329E 04
0.877623	0.830540E 05	0.189464E 03	0.130750E 04
0.887779	0.841622E 05	0.190263E 03	0.134176E 04
0.898005	0.847022E 05	0.191012E 03	0.135117E 04
0.908148	0.965356E 05	0.204252E 03	0.166757E 04
0.918253	0.969613E 05	0.204833E 03	0.168918E 04
0.928277	0.990407E 05	0.240157E 03	0.172274E 04
0.938417	0.112568E 06	0.280308E 03	0.175850E 04
0.948483	0.120050E 06	0.288372E 03	0.182857E 04
0.958531	0.129246E 06	0.304654E 03	0.218273E 04
0.968559	0.140616E 06	0.311794E 03	0.227103E 04
0.978570	0.158393E 06	0.358859E 03	0.241081E 04
0.988571	0.176898E 06	0.377945E 03	0.284285E 04

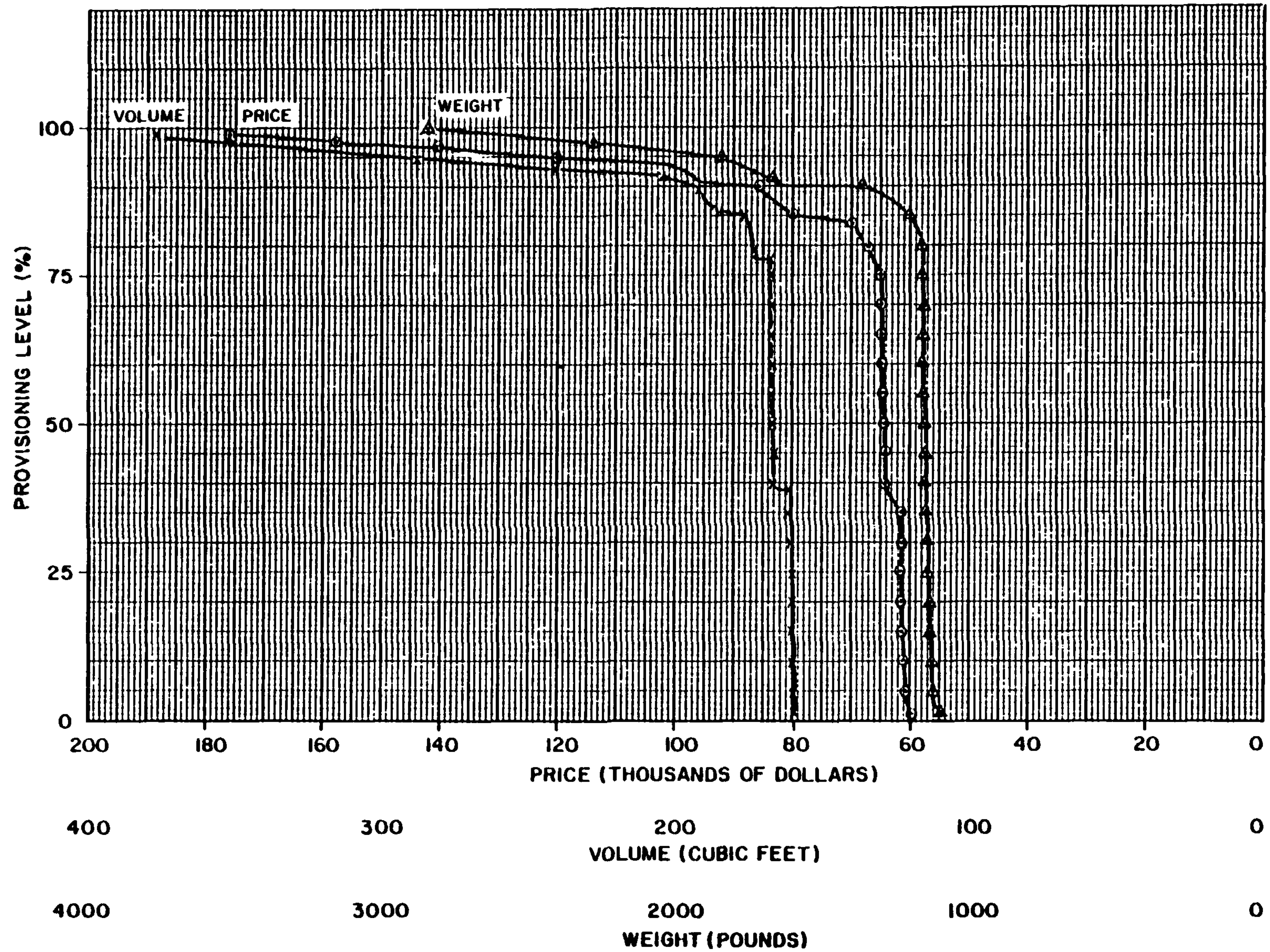


Figure 11. Depot Stock Constraints Graph - Parts Only

TABLE 12. DEPOT STOCK CONSTRAINTS - PARTS AND ASSEMBLIES

Provisioning Level	Price		Cube		Weight	
0.010848	0.150349E	05	0.392251E	02	0.101490E	03
0.020895	0.155660E	05	0.412822E	02	0.105709E	03
0.031672	0.161663E	05	0.452842E	02	0.130850E	03
0.043282	0.163348E	05	0.452983E	02	0.134640E	03
0.055402	0.167365E	05	0.456729E	02	0.141770E	03
0.066727	0.168973E	05	0.457135E	02	0.143440E	03
0.077579	0.168999E	05	0.457597E	02	0.144010E	03
0.088324	0.170709E	05	0.458061E	02	0.146490E	03
0.098606	0.175919E	05	0.465351E	02	0.149810E	03
0.108684	0.200919E	05	0.527166E	02	0.155760E	03
0.121127	0.202719E	05	0.532276E	02	0.171920E	03
0.132902	0.202837E	05	0.532825E	02	0.173440E	03
0.145463	0.203377E	05	0.534757E	02	0.177360E	03
0.158588	0.203496E	05	0.535158E	02	0.178440E	03
0.170339	0.203754E	05	0.535312E	02	0.178630E	03
0.181327	0.214754E	05	0.595312E	02	0.204830E	03
0.195701	0.215250E	05	0.595417E	02	0.205200E	03
0.205911	0.215250E	05	0.595417E	02	0.205200E	03
0.216654	0.215259E	05	0.595571E	02	0.205390E	03
0.227957	0.215276E	05	0.595879E	02	0.205770E	03
0.239850	0.215293E	05	0.596187E	02	0.206150E	03
0.252364	0.215351E	05	0.596367E	02	0.209740E	03
0.265530	0.215601E	05	0.599476E	02	0.218060E	03
0.279133	0.215601E	05	0.599476E	02	0.218060E	03
0.293169	0.217616E	05	0.599531E	02	0.218460E	03
0.306856	0.217703E	05	0.599591E	02	0.219200E	03
0.319764	0.218053E	05	0.599654E	02	0.219750E	03
0.330481	0.218053E	05	0.599654E	02	0.219750E	03
0.343186	0.218098E	05	0.600002E	02	0.220550E	03
0.353728	0.218348E	05	0.600007E	02	0.220580E	03
0.366199	0.218362E	05	0.600052E	02	0.220720E	03
0.378425	0.218425E	05	0.600206E	02	0.221280E	03
0.390388	0.218890E	05	0.600357E	02	0.221650E	03
0.402569	0.219640E	05	0.600362E	02	0.221680E	03
0.414158	0.219669E	05	0.600547E	02	0.222050E	03
0.426080	0.219687E	05	0.600714E	02	0.222300E	03
0.438346	0.219867E	05	0.600746E	02	0.222480E	03
0.450965	0.219867E	05	0.600746E	02	0.222480E	03
0.462927	0.219942E	05	0.600753E	02	0.222590E	03
0.475789	0.219950E	05	0.600907E	02	0.222780E	03
0.487480	0.221200E	05	0.601090E	02	0.223780E	03
0.500128	0.246560E	05	0.661199E	02	0.224710E	03
0.512712	0.251835E	05	0.668836E	02	0.232700E	03
0.525685	0.251985E	05	0.668972E	02	0.233930E	03
0.538986	0.252101E	05	0.669126E	02	0.235050E	03
0.552623	0.253721E	05	0.671876E	02	0.243450E	03

TABLE 12. DEPOT STOCK CONSTRAINTS - PARTS AND ASSEMBLIES (Continued)

Provisioning Level	Price	Cube	Weight
0.563754	0.253729E 05	0.672030E 02	0.253640E 03
0.577042	0.254503E 05	0.673302E 02	0.248460E 03
0.587109	0.256012E 05	0.673794E 02	0.250400E 03
0.598938	0.261050E 05	0.694101E 02	0.252160E 03
0.611681	0.267050E 05	0.734101E 02	0.277160E 03
0.624024	0.269150E 05	0.734612E 02	0.280060E 03
0.635678	0.269453E 05	0.734638E 02	0.280240E 03
0.645820	0.294873E 05	0.795447E 02	0.283970E 03
0.656157	0.300524E 05	0.804336E 02	0.293470E 03
0.666740	0.304031E 05	0.808511E 02	0.301220E 03
0.676910	0.318292E 05	0.870104E 02	0.331690E 03
0.687002	0.369266E 05	0.960930E 02	0.647010E 03
0.697133	0.390680E 05	0.101363E 03	0.708130E 03
0.707203	0.415988E 05	0.103589E 03	0.755529E 03
0.717246	0.431014E 05	0.104806E 03	0.778579E 03
0.727288	0.49[illegible]276E 05	0.112838E 03	0.795629E 03
0.737573	0.559574E 05	0.118096E 03	0.807589E 03
0.747734	0.578809E 05	0.118738E 03	0.832419E 03
0.757898	0.591820E 05	0.152265E 03	0.854625E 03
0.767959	0.630952E 05	0.161336E 03	0.897345E 03
0.778258	0.649266E 05	0.162677E 03	0.925045E 03
0.788330	0.666258E 05	0.168263E 03	0.993925E 03
0.798486	0.726408E 05	0.169672E 03	0.102013E 04
0.808643	0.759098E 05	0.171834E 03	0.105320E 04
0.818665	0.777114E 05	0.173305E 03	0.107723E 04
0.828780	0.791720E 05	0.173999E 03	0.109920E 04
0.838843	0.805065E 05	0.175399E 03	0.112023E 04
0.848971	0.957093E 05	0.190561E 03	0.144524E 04
0.858983	0.100901E 06	0.195449E 03	0.147494E 04
0.869043	0.104448E 06	0.230215E 03	0.152085E 04
0.879162	0.110057E 06	0.235255E 03	0.154992E 04
0.889261	0.112840E 06	0.237764E 03	0.158410E 04
0.899379	0.114322E 06	0.238738E 03	0.159597E 04
0.909451	0.116508E 06	0.240045E 03	0.160605E 04
0.919515	0.137500E 06	0.255446E 03	0.164748E 04
0.929591	0.143827E 06	0.268845E 03	0.171933E 04
0.939631	0.162668E 06	0.284993E 03	0.179976E 04
0.949648	0.182272E 06	0.302122E 03	0.214607E 04
0.959654	0.192066E 06	0.307320E 03	0.222155E 04
0.969686	0.209912E 06	0.326532E 03	0.242598E 04
0.979705	0.225436E 06	0.344404E 03	0.250074E 04
0.989718	0.268917E 06	0.421318E 03	0.301894E 04

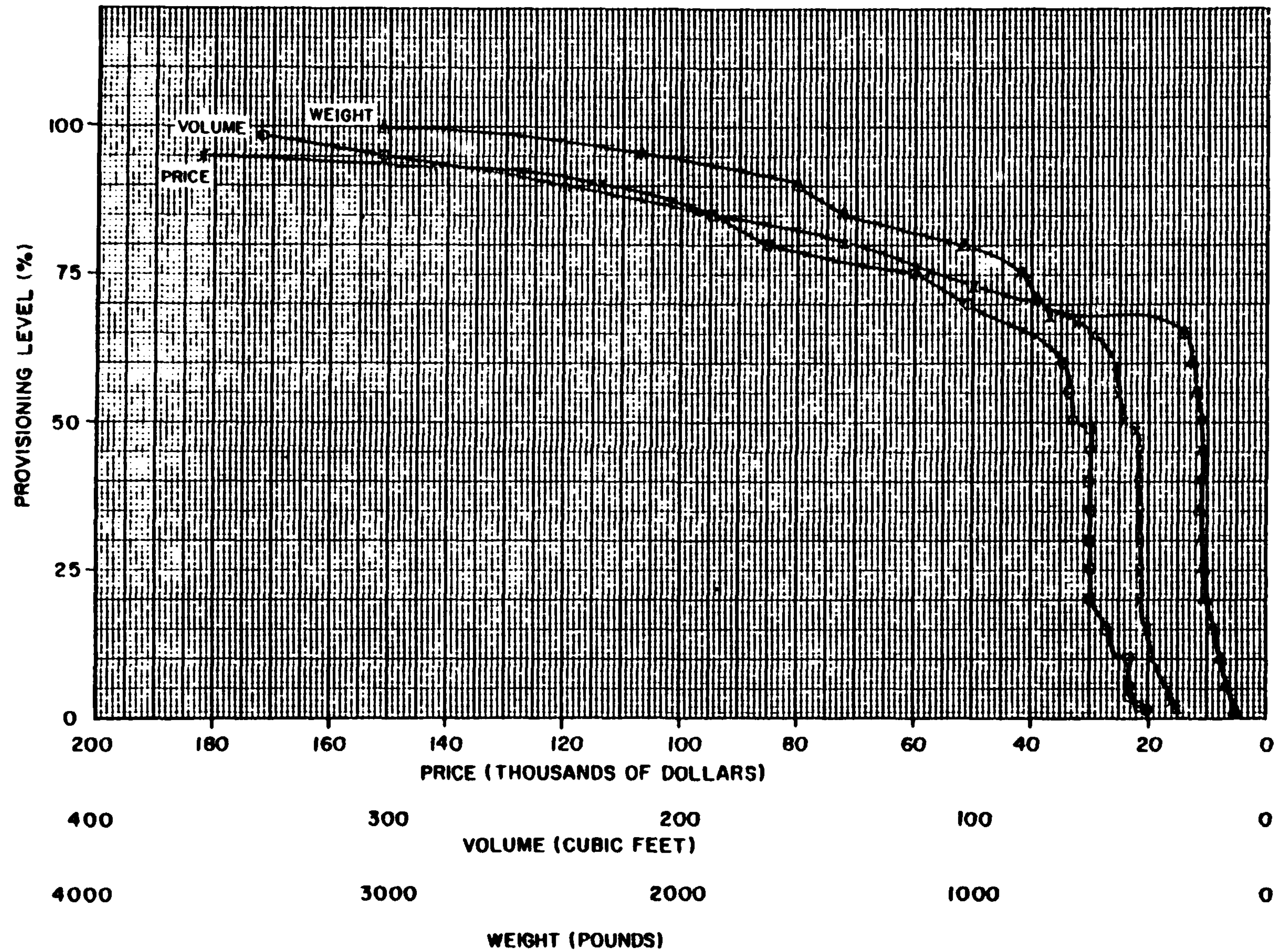


Figure 12. Depot Stock Constraints Graph - Parts and Assemblies

plotted as a function of provisioning level for parts provisioning. Figure 12 illustrates the same information for a depot provisioning both parts and assemblies.

APL CALCULATIONS

Two Allowance Parts Lists for the AN/SPS-40 Radar were analyzed during this program. These were the Allowance Parts Lists dated February 1963 and November 1964. The latter APL did not contain a complete Section B, but only a partial listing of the circuit symbols. This procedure, while indicating the equipment population of the part type, precludes the possibility of identifying the circuit locations of the part type. The exact circuit locations are necessary when considering revisions to the maintenance policy or stocking policy.

The procedures used in analyzing the two above APL's were the same. The initial step was to assign replacement rates to the part quantities shown in the stock number sequence list, Section C of the APL. The part types of FSN, allowed quantities, and replacement rates were transferred to punched cards. The punched cards were inserted, in FSN order, into a deck of cards containing the remaining part types, replacement rates, and population within the equipment. It is necessary to have all parts represented whether the parts are to be spared or not. The card deck containing only shipboard installable parts was used in conjunction with the computer program to determine the associated provisioning level. The older APL dated February 1963 which had a range of 1,161 part types and a depth of 2,132 parts listed in its stock number sequence list was determined to have a provisioning level of 1/2%. The newer Navy APL dated November 1964, which had a range of 1,297 part types and a depth of 2,455 parts listed in

its stock number sequence list, was determined to have a provisioning level of 1.0%.

It was found that the quantities in Section C of the APL included repairable assemblies as well as spare parts. There are several methods of handling the modeling, however, the method chosen was the one which would credit the APL with the greatest possible protection level. The procedure assumes that when an assembly fails it is replaced by the spare assembly after which the spare parts are used and finally the malfunctioned assembly may be completely cannibalized.

The APL (February 1965) contains 2,132 spares listed in Section C as allowed quantities, however, 48 of these spares are for assemblies containing replaceable parts. There are 47 different assemblies and one of the assemblies is allowed two spares. The 48 assemblies contain 3,809 parts which when combined with the other spares listed in the APL make a total of 5,941 spares. The 5,941 spares were used in the APL calculations and yielded 1/2% protection for a three-month period.

The spare parts were calculated to cost $42,278.00 and the cost of the parts within the 48 spare assemblies cost $10,318.00. During previous studies it has been found that assemblies cost approximately five times their parts cost which indicates that the assemblies have an estimated value of $51,590.00. The spare parts and the spare assemblies combined are then valued at $93,867.00 which represents the cost of the allowed quantities specified by the APL. Since there are some parts with unknown cost, the spare parts cost would be increased when the cost of these parts is obtained.

Section VI
DISCUSSION OF PHASE I RESULTS

A result of major interest generated during Phase I of this program is the comparison of recommended spares of the Vitro stock list and the APL. Table 13 contains comparisons of the three stock lists generated for the equipment by Vitro and Navy APL's which are dated Febraury 1963 and November 1964. Since the APL provides for both critical and noncritical parts, the APL should most properly be compared with the Vitro critical/noncritical stock lists. Two of Vitro stock lists are for provisioning parts only, the other is for both parts and assemblies.

The Vitro critical/noncritical stock list for parts only was determined to provide 90% provisioning level for a three-month period and was found to cost $78,058.00. The APL dated February 1963 was found to provide 0.5% provisioning level for a three-month period and cost $93,867.00. Both costs are actually greater than the stated amounts since the cost of approximately 300 - 400 parts are unknown. The APL dated February 1963 did not consider Field Changes 10, 11, and 12 which has the effect of degrading the provisioning level.

The Vitro stock list for parts only in general has greater range and less depth than does the APL except for the items in stock class 5960 where the depth in many cases is greater than the 1963 APL. Of the 1,809 items considered by the Vitro stock list, 324 were not given any spares, 1,310 were given one spare each, and 175 items had a depth greater than one. About 50% of those items with a depth greater than one are found in stock class

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TABLE 13. VITRO STOCK LIST AND APL COMPARISONS

Stock List Identification	Provisioning Level (%)	Overall Depth (Number of Spares)	Overall Range (Number of Part Types Spared)	Number of Part Types Same as APL: With Same Depth	Number of Part Types Same as APL: With Changed Depth	Number of Part Types Not in APL	Number of Part Types in APL Only
Navy APL (Dated Feb. 1963)	0.5	2,132	1,161	NA	NA	NA	NA
Vitro Critical/ Noncritical Parts	90.0	2,103	1,809	1,112	991	683	29
Vitro Critical Parts Only	90.0	1,741	1,502	865	649	343	33
Vitro Critical Parts (Minimum Depth)	93.9	2,337	2,043	925	1,208	911	9
Navy APL (Dated Nov. 1964)	1.0	2,455	1,297	NA	NA	NA	NA
Vitro Critical/ Noncritical Parts	90.0	2,103	1,809	1,176	936	507	34
Vitro Critical Parts Only	90.0	1,741	1,502	1,052	712	369	38
Vitro Critical Parts (Minimum Depth)	93.9	2,337	2,043	1,009	1,105	771	7
Vitro Critical/ Noncritical Parts and Assemblies	94.1	1,698	1,442	825	790	518	418

5960 which consists primarily of tubes and diodes. There were 1,112 part types with the same depth in the two stock lists. The two stock lists had 60 to 80 percent agreement in the categories of resistors and capacitors found in stock classes 5905 and 5910, respectively. Of the 991 part types which had a changed depth in the Vitro stock list, it was found that 268 part types had lesser depth than the APL and 738 had an increased depth over the APL. Much of the increased depth is due to mechanical items in stock classes 3010 through 3110 and Lockheed part numbers which were not provisioned by the APL. There were 29 part types which were given spares by the APL but were not given spares in the Vitro stock list. There were 297 part types which were not given spares by either the APL or the Vitro stock list.

A comparison was also made between the four Vitro stock lists and the newer APL of November 1964 which has been up-dated to include Field Changes 1 through 12. This APL had a provisioning level of 1% and a range of 1,297 and a depth of 2,455 items. The most useful comparison is between the APL and the Vitro critical/noncritical stock list for parts and assemblies. This Vitro stock list contained 518 items not in the APL and conversely the APL contained 418 items not spared in the Vitro stock list. Four hundred and four of the 418 items were not spared by the Vitro stock list because they are assembly parts. The Vitro stock list had 825 items which had the same allowed quantity as the APL and 790 items with a changed depth.

Table 14 shows the 518 items which were provisioned in the Vitro stock list for parts and assemblies which were not allowed spares by the November 1964 APL. Table 15 shows the 14 items which were provisioned in the November 1964 APL but were not allowed spares by the Vitro stock list for

TABLE 14. PARTS PROVISIONED BY VITRO STOCK LIST - NOT IN APL (1964)

3010-725-8019	4140-837-9898	5340-677-0402	5905-256-3361
3010-733-5276	4140-893-0145	5340-685-7023	5905-549-5602
3010-983-6007	4310-073-3573	5340-725-0969	5905-552-2442
3020-060-7926	4320-620-7199	5340-754-1899	5905-731-8358
3020-060-7927	4720-873-2683	5340-812-0474	5905-731-8361
3020-060-7928	4720-873-2684	5340-820-6748	5905-801-5633
3020-580-2204	4720-873-2688	5340-825-8229	5905-801-5642
3020-620-7195	4720-873-2689	5355-049-8572	5905-801-5852
3020-731-4417	4730-684-3579	5355-556-0145	5905-801-6212
3020-731-4418	4730-720-0461	5680-020-2790	5905-812-3170
3020-731-4419	4730-815-6976	5840-020-2772	5905-828-4098
3020-731-4420	4730-872-9213	5840-020-2785	5905-837-7776
3020-731-4425	4820-444-9775	5840-023-1955	5905-839-4637
3020-731-4426	4820-814-8448	5840-055-1731	5910-087-0922
3020-731-4427	4820-860-4282	5840-056-7033	5910-101-4063
3020-731-4428	4920-792-9219	5840-064-8308	5910-101-4679
3020-731-4429	5305-543-2777	5840-065-9716	5910-126-9170
3020-731-4431	5305-543-2789	5840-073-2235	5910-644-6224
3020-732-4902	5310-582-6300	5840-073-2236	5910-666-5585
3020-732-4903	5310-613-4287	5840-073-2237	5910-666-6117
3020-732-4906	5310-655-7511	5840-073-2238	5910-725-2646
3020-732-8530	5310-680-9492	5840-439-6340	5910-899-1398
3020-769-1087	5310-687-2626	5840-713-5382	5915-076-0129
3020-791-5484	5315-298-0950	5840-732-8505	5915-076-2145
3020-801-4229	5315-687-5126	5840-758-0898	5915-715-2350
3020-801-4230	5315-731-9233	5840-769-1078	5915-798-4963
3020-801-4231	5315-812-3035	5840-787-2755	5915-818-3391
3020-801-4232	5315-840-9853	5840-787-2756	5915-818-3392
3020-820-9262	5330-171-9361	5840-787-3709	5915-818-5596
3020-820-9263	5330-290-9481	5840-787-3723	5915-860-0826
3020-839-8972	5330-530-1991	5840-789-5240	5920-281-0210
3020-839-8973	5330-530-2008	5840-798-4961	5920-281-0224
3020-839-8974	5330-585-3217	5840-838-3385	5920-296-5369
3020-839-8975	5330-713-5370	5840-838-3386	5920-799-7979
3020-839-8976	5330-801-0775	5840-860-0842	5920-799-8574
3020-841-7098	5330-879-6842	5840-860-0855	5920-799-8579
3020-879-4036	5330-950-1162	5840-872-9209	5930-019-8172
3020-985-0201	5340-073-2232	5840-872-9214	5930-019-8173
3040-444-9779	5340-073-2233	5840-966-7707	5930-019-8175
3040-580-9749	5340-073-2234	5840-966-7708	5930-615-7882
3040-769-1079	5340-286-9469	5840-976-3268	5930-635-1522
3040-769-1080	5340-513-2262	5840-976-4889	5930-655-1522
3040-769-1082	5340-585-1660	5840-991-1496	5930-713-5282
3110-440-3885	5340-585-9835	5840-991-3378	5930-713-5317
3110-702-1599	5340-598-1228	5840-715-9422	5930-713-5318
3120-713-4651	5340-630-6486	5905-170-2004	5930-837-8058
3120-715-9542	5340-631-6033	5905-195-6800	5930-860-0846

TABLE 14. PARTS PROVISIONED BY VITRO STOCK LIST - NOT IN APL (1964) (Continued)

5930-873-2690	5945-056-6771	2329F0045-4	4400B0643
5930-878-3159	5945-629-3647	2329F0045-5	4400B0714
5935-020-5791	5950-552-8403	2329F0045-6	4400B0715
5935-222-6457	5950-552-8705	2329F0045-7	4400B0716
5935-237-6445	5950-553-5694	2329F0045-8	4400B0717
5935-258-6045	5950-731-1886	2329F0045-9	4400B0722
5935-259-0337	5950-789-5238	2329F0045-10	4400B0744
5935-259-0367	5950-837-5822	2329F0045-11	4400B0745
5935-439-6892	5950-838-1938	2329F0045-12	4400B1354
5935-491-6525	5950-838-1940	2329F0094	4400B1367
5935-539-2651	5959-819-6860	2333C0012	4400B1369
5935-583-8689	5960-264-3004	2333C0031	4400B1370
5935-586-7217	5960-548-6530	2344B0066	4400B1371
5935-615-1108	5960-556-2621	2344B0067	4400B1372
5935-617-2219	5960-581-5603	2344C0042	4400B1373
5935-636-5905	5960-586-7056	2344C0166	4400B1374
5935-665-7227	5960-682-0885	2344C0166-2	4400B1375
5935-677-8054	5960-810-4928	2344C0184	4400B1444
5935-713-4200	5970-151-8012	2344D0144	4400B1445
5935-725-1345	5975-966-7706	2344D0179	4400B1463
5935-726-4150	5999-060-8643	2344D0183	4400B1463-2
5935-729-8036	5999-086-8567	2344F0090	4400B1477
5935-731-1876	5999-713-5384	2344F0163	4400B1479
5935-731-1885	5999-731-1878	2344F0164	4400B1509
5935-752-2636	5999-738-2350	2344F0165	4400B1703
5935-755-5836	5999-755-2918	2630B0349	4400B1705
5935-860-0824	5999-789-2197	2730B0354	4400B1709
5935-860-0825	5999-837-9494	2630B0360	4400B2126
5935-879-5113	5999-837-9495	2630B1669	4400B2129
5935-879-5116	6105-446-9772	2630D0007	4400C0017
5935-985-2005	6125-245-7136	2630D0092	2344C0159
5935-991-3377	6145-080-6515	2630D0142	2344C0159-2
5940-258-1931	6145-080-8733	2630D0169	4400C0434
5940-355-4692	6145-754-8159	2630D0433	4400C0605
5940-500-5373	6625-728-6029	2630F0005	4400C0641
5940-500-5378	6625-728-6030	29004	4400C0646
5940-500-5381	6680-801-2211	3239F0094	4400C0647
5940-500-5388	6680-801-2212	39905	4400C0650
5940-502-4522	6685-735-4689	41388	4400C0712
5940-502-8469	7901-406-2037	4400B0152	4400C1265
5940-518-9611	1940B1509	4400B0198	4400C1265-2
5940-542-8546	2329B0019-2	4400B0262	4400C1266
5940-542-8547	2329B0049	4400B0314	4400C1267
5940-577-7462	2329D0083	4400B0340	4400C1267-2
5940-613-2627	2329F0024	4400B0436	4400C1268
5940-723-3501	2329F0045-2	4400B0493	4400C1279
5940-787-3726	2329F0045-3	4400B0549	4400C1367

TABLE 14. PARTS PROVISIONED BY VITRO STOCK LIST - NOT IN APL (1964) (Continued)

4400C1384	CTC2045-1	5999-022-9963
4400C1384-2	HH33573	5999-713-4349
4400C1384-3	JV40A2H6A1	5999-837-5826
4400C1384-4	K46738-8-2	5999-837-9496
4400C1645	MS21922-4R	5999-950-2885
4400C1864	MS21923-8C	6210-504-1617
4400C1864-2	MS21923-12C	6210-553-1711
4400C1864-3	MS91528-1	6210-553-8219
4400C1864-4	MS91528-11-2	6210-836-2564
4400C1866	MS3102E14S9	6625-088-5411
4400C1866-2	RB16CER3400	6625-649-3274
4400C1866-3	RC08GF101K	6625-715-9431
4400C1860-4	RC20GF121K	6625-733-2745
4400C1866-5	RC20GF151K	6625-733-2746
4400C1866-6	RC20GF223K	6625-733-2748
4400C2017	RC20GF331K	6625-820-8458
4400D0904-4	RC42GF102K	6625-820-8460
4400D0904-5	RW33G620	6625-820-8461
4400D1001	SSG350-126	6625-838-0147
4400D1214	TMI-433	6625-838-0148
4400D1553	0000-000-0000	6625-872-9212
4400D1716	8-8FTX	6625-873-2680
4400F0524	10-183	6645-840-5693
4400F0525	12-8FTX	1940B0364
4400F0526	204-SZZC	2630B0378
4400F0916	602D4	2630B0412
4400F1213	2045-1	263B1687
4400F1289	39904-4	4400B0106
..00F1291	39904-5	4400B0483
4400F1293	39916	4400B0969
4400F1295	5133-25W	39913
4400F1299	5330-531-5375	39914
4400F1300	534-798-4968	39915
4401B0460	5355-881-4240	39916
4401B0461	5840-715-9531	39917
4401B0462	5840-891-8028	39919
4401B0463	5845-787-2757	41888
4401D0645	5905-190-8874	41889
AMMS1KC07	5905-279-2530	41890
AN3436-5-3	5910-807-2585	C19394-1
AN3436-5-5	5910-823-1204	ST42C
AN924-D	5910-825-1637	10-489
AN924-4D	5910-826-5466	2114
C147-3	5930-715-9426	4592
C147-4	5930-715-9580	19399-6
C147-6	5935-552-7613	1111-111-1111
CQ05A1VE105K	5960-273-2415	2222-222-2222
CQ22C1SS103K		

TABLE 15. PARTS PROVISIONED BY APL (1964) - NOT IN VITRO STOCK LIST

5330-265-9841
5910-618-1635
5910-633-9280
5935-240-8166
5935-552-6842
5935-552-7720
5935-813-4722
5935-991-3375
5950-860-0818
5950-860-0819
5950-860-0820
5960-549-7670
5999-731-1881
6210-264-7010

TABLE 16. PARTS PROVISIONED BY APL (1964) - DELETED FROM VITRO STOCK LIST

3030-360-0829	5905-254-7100	5905-279-3519	5905-577-1761
3110-097-9611	5905-257-0926	5905-279-3521	5905-577-6442
3110-198-2930	5905-264-8753	5905-279-3837	5905-577-7427
3110-806-4946	5905-279-1718	5905-279-5476	5905-581-7873
5330-054-6904	5905-279-1751	5905-283-7402	5905-681-8817
5330-171-9916	5905-279-1753	5905-299-1971	5905-681-8819
5330-265-1095	5905-279-1754	5905-299-2000	5905-681-9969
5330-285-9836	5905-279-1877	5905-299-2011	5905-683-2197
5840-894-3033	5905-279-1881	5905-299-2030	5905-683-2206
5840-955-4946	5905-279-1883	5905-518-9223	5905-683-6792
5905-060-7570	5905-279-1897	5905-542-7804	5905-686-3129
5905-102-2740	5905-279-2019	5905-552-6018	5905-686-3379
5905-171-2001	5905-279-2518	5905-553-2202	5905-686-9994
5905-190-3837	5905-279-2626	5905-556-4086	5905-726-4413
5905-192-0450	5905-279-2650	5905-556-4101	5905-752-3377
5905-192-0649	5905-279-2651	5905-556-5231	5905-732-4894
5905-195-5524	5905-279-2673	5905-556-6420	5905-732-4895
5905-195-5546	5905-279-3494	5905-556-7015	5905-732-8522
5905-195-6453	5905-279-3502	5905-577-0437	5905-752-3567
5905-195-6791	5905-279-3511	5905-577-0448	5905-752-3597
5905-249-3642	5905-279-3514	5905-577-1615	5905-752-3973

TABLE 16. PARTS PROVISIONED BY APL (1964) - DELETED FROM VITRO STOCK LIST (Continued)

5905-752-6575	5905-846-9676	5910-681-7347	5910-883-5716
5905-752-6583	5905-879-6899	5910-686-6005	5910-892-7700
5905-800-3469	5905-879-7127	5910-686-7100	5910-898-9019
5905-800-3470	5905-893-5198	5910-688-3007	5910-899-1897
5905-800-3472	5910-051-3825	5910-702-9928	5910-899-6553
5905-801-5687	5910-051-8104	5910-713-5243	5910-965-5486
5905-802-6730	5910-081-6985	5910-725-5423	5910-990-6855
5905-805-0998	5910-088-3113	5910-726-8695	5915-950-1149
5905-807-6297	5910-161-4490	5910-752-4499	5930-635-1522
5905-808-9774	5910-174-5105	5910-806-2716	5930-787-3714
5905-810-9349	5910-280-7406	5910-806-4328	5930-845-5840
5905-811-9878	5910-284-4050	5910-807-1543	5935-020-8931
5905-812-2734	5910-519-6698	5910-807-9409	5935-064-8528
5905-821-2737	5910-542-7489	5910-812-2747	5935-149-3483
5905-812-2742	5910-542-7491	5910-812-2748	5935-201-7043
5905-812-2743	5910-553-7147	5910-812-3918	5935-201-7922
5905-812-2744	5910-583-0735	5910-812-3919	5935-259-0388
5905-812-3171	5910-583-0878	5910-814-3850	5935-552-4594
5905-812-3177	5910-583-1776	5910-815-4118	5935-721-2675
5905-812-3178	5910-615-9812	5910-818-9758	5935-786-1217
5905-812-3179	5910-636-3824	5910-820-6115	5935-787-4832
5905-818-1990	5910-636-4271	5910-821-4479	5935-804-7447
5905-823-3379	5910-642-6787	5910-823-1512	5935-812-6342
5905-833-5818	5910-643-8713	5910-823-1538	5935-812-6346
5905-837-7951	5910-646-4973	5910-823-1657	5935-841-8092
5905-837-7952	5910-648-8030	5910-825-7342	5945-080-3432
5905-837-7954	5910-648-9534	5910-829-3305	5945-615-8418
5905-837-7955	5910-648-9537	5910-833-9542	5945-820-5650
5905-837-9899	5910-648-9539	5910-834-5003	5950-416-6504
5905-837-9900	5910-649-2946	5910-835-3912	5950-473-5646
5905-837-9901	5910-649-3154	5910-835-6645	5950-542-9797
5905-837-9902	5910-649-5176	5910-838-2394	5950-617-4860
5905-838-1262	5910-655-0137	5910-839-5734	5950-645-4268
5905-838-1263	5910-668-0729	5910-840-0148	5950-713-4293
5905-838-3838	5910-668-3129	5910-842-2302	5950-713-4296
5905-840-0744	5910-668-4582	5910-848-9092	5950-713-4297
5905-840-0748	5910-668-8167	5910-849-5264	5950-732-8507
5905-841-0282	5910-668-8168	5910-849-6155	5905-732-8508
5905-841-3114	5910-676-8292	5910-860-0828	5950-788-1418
5905-841-3122	5910-681-7124	5910-860-0831	5950-798-4955

TABLE 16. PARTS PROVISIONED BY APL (1964) - DELETED FROM VITRO STOCK LIST (Continued)

5950-798-5656	5950-818-0217	5950-860-0810	5960-804-6777
5950-798-5657	5950-818-0218	5950-860-0811	5960-806-1094
5950-798-5658	5950-818-0219	5950-860-0821	5960-809-9318
5950-798-5659	5950-818-0221	5950-860-3445	5960-810-2763
5950-798-5663	5950-818-0222	5950-872-9217	5960-811-3372
5950-798-5664	5950-818-0225	5950-873-2691	5960-812-9996
5950-798-5665	5950-818-3680	5955-796-2757	5960-814-7566
5950-798-5667	5950-818-3681	5955-797-7627	5960-824-9951
5950-798-5669	5950-818-3682	5955-799-1462	5960-837-7262
5950-798-5670	5950-818-3683	5955-811-7886	5960-838-2033
5950-798-5671	5950-818-3684	5955-811-7887	5960-838-5916
5950-798-5673	5950-818-3685	5955-812-0970	5960-840-3561
5950-798-5674	5950-818-3686	5955-812-0971	5960-850-8450
5950-798-5675	5950-818-3687	5955-812-0972	5960-878-4284
5950-798-5676	5950-818-3688	5955-812-0973	5960-878-6590
5950-798-5677	5950-818-3689	5955-812-0974	5960-878-6591
5950-798-5678	5950-818-3690	5955-812-0975	5960-878-6592
5950-798-5679	5950-818-3692	5955-818-3695	5960-983-5990
5950-798-5681	5950-818-3996	5960-474-6710	5960-983-7158
5950-799-0[illegible]24	5950-818-3997	5960-542-7308	5960-990-4581
5950-799-0535	5950-818-3998	5960-549-0994	5985-649-8582
5950-799-5[illegible]3	5950-818-4000	5960-552-9852	5999-752-3269
5950-799-5949	5950-818-4001	5960-556-9314	5905-192-0619
5950-801-1524	5950-818-4002	5960-661-0062	5905-518-7506
5950-801-1525	5950-818-4003	5960-682-9250	5905-556-3735
5950-801-7672	5950-818-4004	5960-685-8465	5905-556-3738
5950-802-1805	5950-819-3924	5960-712-3939	5905-683-3876
5950-802-4211	5950-819-6860	5960-712-3952	5910-080-2938
5950-804-9363	5950-838-0142	5960-712-7696	5910-556-9440
5950-805-5185	5950-838-1914	5960-727-5622	5910-581-8114
5950-810-4611	5950-838-1915	5960-729-1712	5910-583-1587
5950-812-2759	5950-838-1916	5960-729-8150	5910-822-5684
5950-812-2760	5950-838-1917	5960-751-7246	5910-827-0175
5950-815-0537	5950-838-1918	5960-752-0182	5910-833-7797
5950-818-0208	5950-838-1927	5960-752-0401	5910-865-4510
5950-818-0210	5950-838-1929	5960-752-0432	5935-020-2758
5950-818-0211	5950-838-1937	5960-773-7925	5945-733-5275
5950-818-0213	5950-838-1948	5960-783-7427	5950-860-3382
5950-818-0214	5950-860-0807	5960-788-8644	5950-860-3446
5950-818-0216	5950-860-0809	5960-791-0159	5950-860-3448

parts and assemblies. Table 16 shows the 404 items which were provisioned in the November 1964 APL but were deleted from the Vitro list because they were contained within the 84 specified manufacturer repairable assemblies.

The APL and the Vitro stock list (critical/noncritical parts) provisioning levels versus time are shown graphically in figure 13. The graph illustrates the rapid decline in provisioning level with time for the APL. There is so little difference between the February 1963 APL shown in figure 13 and the February 1964 APL that the graphic scale prevents them from being distinguished.

The provisioning level determined for the APL is extremely low which appears to contradict actual conditions since there would never be sufficient spares available to keep the AN/SPS-40 in operation. It is believed that there are two forces at work which lessen the effect of the calculated APL provisioning level on the equipment's ability to obtain the required replacement parts. These forces are that ships are usually at sea for a two to three week period rather than for three months and that the ship is provisioned by means of a COSAL rather than an APL. The graph shows that 43% to 22% provisioning level is applicable for the two to three week period. Since the ship is stocked by the COSAL, many parts are specified in order to supply all the equipment on board. It is possible that the AN/SPS-40 is consuming parts which were placed on board for equipments other than the AN/SPS-40. The APL was compared with the 30 June 1964 COSAL for the USS Furse (DD 882) and it was found that the COSAL increased depth or supplied parts not provisioned by the APL for approximately 20% of the items in the AN/SPS-40. These stock room spares would have the effect of decreasing stock-outs on the AN/SPS-40.

The above two conditions tend to lessen the effect of insufficient spares for the AN/SPS-40 except that the COSAL quantities would not help

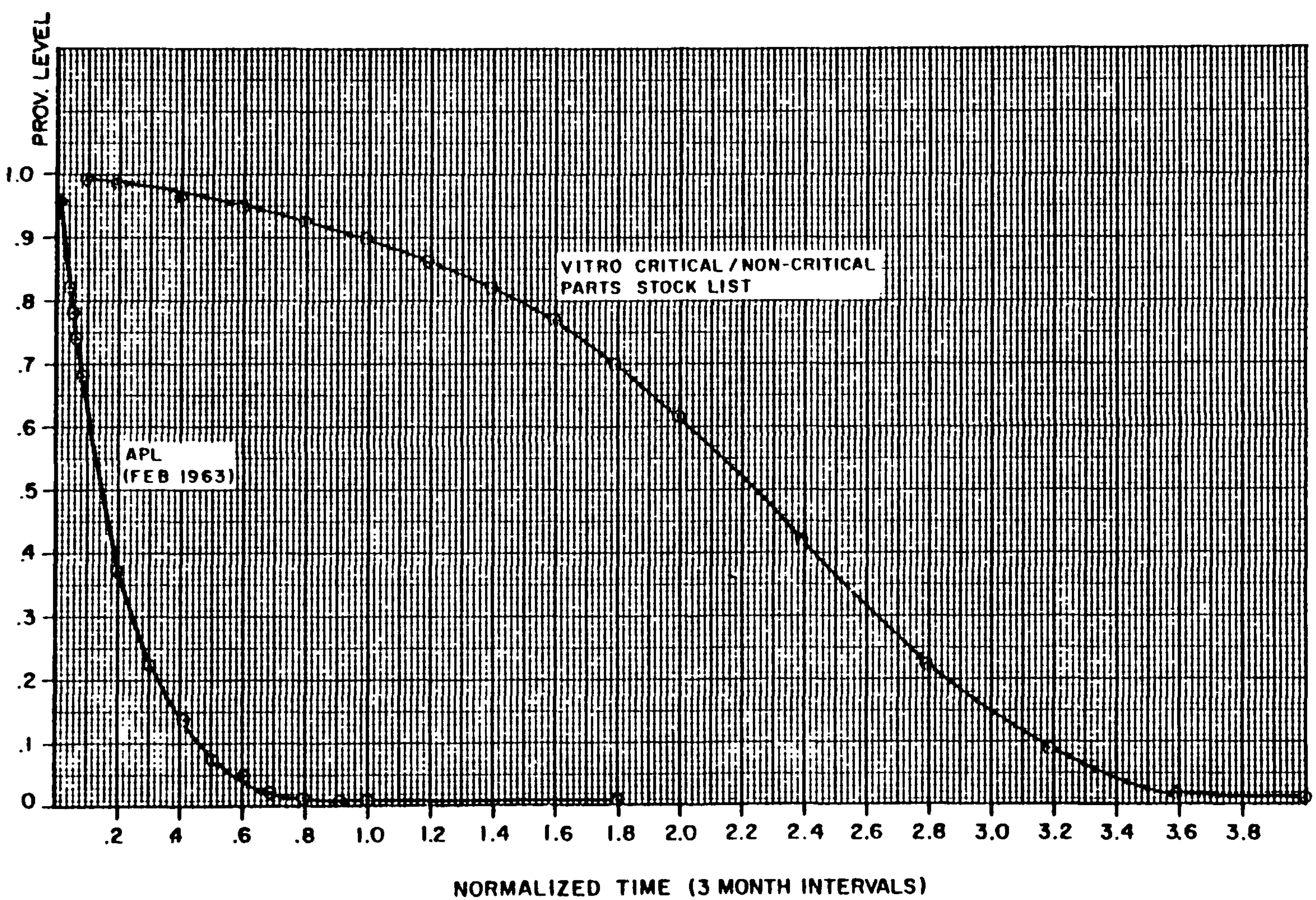

Figure 13. Vitro Stock List - APL Comparison Graph

in cases where a part type is unique to the AN/SPS-40. In the case of unique parts, stock-outs would occur more frequently, which appears to be verified by field reports.

The question arises as to why the APL has a provisioning level of less than 1% when it has greater range and depth than the 90% Vitro provisioning level stock list. While both lists have taken the population of a part type into consideration, the Vitro stock list also considers the replacement rate to which, in many cases, the APL appears to be insensitive. Table 17 illustrates a dozen part types which have not been provided with any spares by the APL. These items have a large enough replacement rate to limit the maximum provisioning level to 33% even if all other parts were protected to 100%. The table shows how a few parts can have an astonishingly large effect on the provisioning level calculation.

The importance of a complete equipment part inventory is shown by this example as well as justifying effort expended on the equipment manual which produced 492 circuit symbol changes to the ESO data file. Three of the items, the pump sub-assembly, the power supply, and the 5970 stock class capacitor, have appeared on the demand data cards since these items are unique to the AN/SPS-40. The fact that these items were demanded tends to justify the rates used in the Vitro calculation and that these parts should be provided spares by the APL.

As has been shown by table 17, the APL does not supply a sufficient number of certain parts if the equipment is to be completely repaired by the technician. On the other hand, if the EMEC specified assemblies and units are not repaired by the technician, then the APL does not provide enough spare assemblies. The APL has a total of 53 spare assemblies while

TABLE 17. HIGH RATE PARTS

FSN	Name	Repl. Rate Per 10^6 hrs. For Population	Protection For Zero (0) Spares	Cumulative Protection
N 3030-860-0829	Belt	50	.8963	.896
N 3030-860-0830	Belt, Drive	50	.8963	.803
3110-702-1599	Bearing	26	.9273	.744
N 4320-620-7199	Pump	15	.9678	.720
N 4320-733-5279	Pump Sub-Assembly	26	.9432	.680
R 4730-720-0461	Sleeve	18	.9613	.653
4820-814-8448	Valve	15	.9678	.632
5840-732-8505	Power Supply	28	.9394	.594
5910-829-3305	Capacitor	24	.9480	.563
N 5930-873-2690	Switch Assembly	34	.9287	.523
N 5935-731-1876	Socket Assembly	131	.7497	.392
N 5970-848-8455	Capacitor	75	.8483	.332

the Vitro stock list recommends 141 spare assemblies in order to obtain a 90% provisioning level for a three-month stock period.

After a detailed analysis by EMEC Radar Section of the Vitro stock results for the AN/SPS-40, two changes in the maintenance policy were suggested for the Critical/Noncritical parts and assemblies stock list. The first change suggested was that a pulse transformer with circuit symbol 4T2, Federal Stock Number 5950-732-8525, be allowed only one spare instead of three. The second change was that certain specified parts be stocked instead of the following assemblies:

Circuit Symbol	FSN	Name
4A2	5840-023-1955	Grid Cavity
4A3	5840-065-9716	Plate Cavity
11	5840-056-7033	Duplexer

In complying with the recommended changes the above assemblies would not be stocked but instead the following twenty parts would be added to the critical/noncritical parts and assemblies stock list:

FSN	Nomenclature	Spares
3030 860 0829	Belt	2
3030 860 0830	Belt	2
4720 872 9215	Tube Assembly	1
5315 720 6460	Roll pin	1
5330 054 6904	Packing	1
5330 171 9916	"O" Ring	1
5330 265 1095	"O" Ring	1
5330 285 9836	Gasket	1
5840 733 5283	Load Assembly	1

FSN	Nomenclature	Spares
5840 733 5291	Socket	1
5840 987 1496	Tee Section	1
5840 991 8691	Tee Section	1
5905 577 6442	Resistor	1
5910 860 0828	Capacitor	1
5940 893 0951	Contact	1
5999 984 7047	Gasket	1
LEC 4400 B 2086	Gasket	1
LEC 4401 B 0432	Gasket	1

The resulting stock list would have a protection level of 93%, cost $100,200.00, weight 711 pounds, and have a volume of 121 cubic feet. The changes to the Critical/Noncritical parts and assemblies stock list reduced the provisioning level by 1%, the cost by $31,100.00, the weight by 620 pounds, and the volume by 34 cubic feet. This stock list represents the results of the most detailed analysis of the maintenance capability of the ship.

Section VII
PHASE I CONCLUSIONS AND RECOMMENDATIONS

The procedures discussed for determining the stock list for critical/noncritical parts and assemblies sparing are recommended for use by the Navy for producing the allowance quantities specified on APL's. This procedure is recommended since it considers the technician skill level, the availability of on-site test equipment, and current Navy maintenance philosophy. The EMEC adjusted parts and assemblies stock list represents the most accurate information available on the AN/SPS-40 Radar at this time. The parts and assemblies stock list is however, more expensive. As shown in table 18 there is about a 60% increase in cost when the specified assemblies and units are stocked rather than performing the repairs aboard ship. The cost of training and maintenance man-hours required have not been determined so it is not known which is the more economical procedure from the overall viewpoint of Navy. The only conclusion is that the benefits derived from replacing instead of repairing assemblies aboard ship is paid for by the logistics system. Even this cost is not the whole story since an additional number of spare assemblies would have to be bought to provide for those involved in the repair facility's turn-around pipeline. The cost values shown in table 18 which were generated during this study represent approximate values due to the fact that there were items provisioned for which no cost figures were available. It is estimated that this may increase the table values by 10 to 20 percent.

TABLE 18. SPARES COST ANALYSIS

Location	All Repairs Aboard Ship		Selected Repairs Aboard Ship	
	Total Cost	Cost per Equipment	Total Cost	Cost per Equipment
Ships (84)	$6,556,872.00	$78,058.00	$11,031,300.00	$131,325.00
Support Ship (14)	1,018.206.00	12,122.00	1,690,752.00	20,128.00
Depots (2)	700,196.00	8,336.00	1,138,048.00	13,548.00
Totals	$8,275,274.00	$98,516.00	$13,860,100.00	$165,001.00

Values may be 10-20% higher than shown due to fact that no cost figures were available for some provisioned items.

The procedures used require replacement rates. Replacement rates are considered to be the most appropriate type of information for the purpose of calculating spare requirements. It is felt that demand data should be used only when there are two years of data available, part operating times can be determined, and the part being considered is a part peculiar, i.e., the equipment in which it was used can be identified. Mean rates are not considered to be a major draw back, since the Navy is in an excellent position through its various data analysis systems to provide its own up-dating on replacement rates.

It has become evident during this program that in order to produce a realistic stock list the Navy's maintenance policy must be settled before the AFL can be properly generated. Of utmost importance are those decisions which specify modules or assemblies which are to be thrown away and those which are to be repaired. Next, the location or echelon of repairs must be decided since the location of replacement spare piece parts is dependent upon this decision.

There has been much discussion recently in the area of logistics concerning the stocking of critical items. One recommendation resulting from these discussions has been that critical and noncritical items be provisioned at different levels. The problem area is generated here by the fact that a given Federal Stock Number will have both critical and non-critical applications. The stock rooms aboard ships do not reserve parts for critical application only, but issue parts on a first requirement-first-serve basis. In order to make critical item stocking practical, a method of reserving items by the stock room must be initiated throughout the fleet. Judging from the results obtained on the AN/SPS-40 and the minor savings

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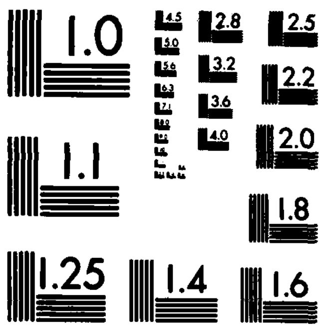

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

which would be involved, such a procedure does not appear to be justified.

Another procedure that has been suggested is the stocking of at least one spare for every critical part type application. It appears that some modification to such a procedure would be practical in order to avoid stocking expensive items for which there is only a slight requirement. For example, circuit symbol 4A6 which is a drive assembly in the AN/SPS-40 costs $1,400.00. The drive assembly is expected to have only 0.7 replacements per year of radar service. The ships (NOT including support ship and depot allowance) would have to stock $117,600.00 worth of drive assemblies if one were allowed aboard each ship. At the end of 10 years of service life there would remain $107,800.00 worth of drive assemblies unused. It would take 120 years for the radars to consume the stock quantities of one per ship. To avoid such problem areas it is suggested that the criterion be to stock at least one spare for each critical item unless the item cost was greater than $50.00. In this case the item would not be stocked on board unless at least one or more were expected to be replaced during the service life of the equipment. For all those items which were excluded under the above conditions, it would be mandatory to stock those critical items aboard support ships and at depots.

One of the criteria to be applied in judging the feasibility and utility of the provisioning procedure is that it responds to the control factors of stock and maintenance policy, part rates, and part population. The results presented in tables 1 and 13 demonstrate that the provisioning procedure is sensitive in range, depth, cost, weight, and cube in the five types of stock and maintenance policies investigated during Phase I. The comparison between the Vitro stock lists and the APL's illustrate the

program's sensitivity to the rates in establishing the provisioning level. Investigation of the stock lists (tables A-1, A-2, A-3, and A-5) shows that the stock quantities are realistically influenced by the part populations. The above discussion is not presented with the intention of proving the generated stock lists to be accurate, but it does show that the provisioning procedure is adequately responsive to desired control factors. To settle the question of accuracy would require a detailed analysis of equipment stock requirements over an extended period of time.

Section VIII
PHASE II
INTRODUCTION

The preceding seven sections have discussed in detail the work accomplished under Contract N189(181)58090A, Phase I. The effort described in those sections was directed primarily toward generating the provisioning procedures, developing a computer program to perform the necessary mathematical operations, and comparing the results of various stocking policies.

During the performance of the above effort, over 1,600 changes were made to the provisioning parts list by Vitro which were determined by means of comparison with the AN/SPS-40 manual parts list. It was recognized that further work in this area was needed but was prevented by contract limitations. EMEC and ESO undertook the effort to develop a complete and accurate parts list for the AN/SPS-40 Radar during the period of April to June 1965 utilizing the Vitro inputs and Lockheed inputs.

At the beginning of Phase I the February 1963 APL identified 9,787 circuit symbols. Over 1600 changes were made by Vitro to this listing, however, only 364 new circuit symbols were added bringing the total for the Phase I effort to 10,151. ESO and Lockheed added 1,033 new circuit symbols after the end of Phase I making a total of 11,184 circuit symbols which were used to produce the June 1965 APL. Forty of the 11,184 were found to have been deleted by Field Change No. 12 which then produced a parts list of 11,144 part applications within the AN/SPS-40. EMEC made a final adjustment of 585 new circuit symbols which produced a total of 11,729.

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Both listings of 11,184 and 11,729 were applied to the Phase II effort.

The following sections of this report present a discussion of the Phase II logistic effort performed on the AN/SPS-40 Radar under Contract N189(62678)60125A using the new provisioning parts list. EMEC directed that the combined effort under Contract N189(181)58090A and Contract N189(62678)60125A be incorporated into one report so that a continuous and complete disclosure of all work on the provisioning of the AN/SPS-40 Radar be contained under one cover.

Section IX
SUMMARY OF WORK

The effort under Phase II involved three general areas which were (1) to determine the provisioning level of the 4 June 1965 APL, (2) to determine the provisioning level of the EMEC APL, and (3) using the EMEC approved parts list to determine stock lists for the equipment, support ship, and depot. The latter effort was to be accompanied by parts lists in circuit symbol order and Federal Stock Number order.

Since this additional work closely paralleled the initial effort, the procedures described in Section III, Input Data, and Section IV, Computer Program, also apply to the work performed under Phase II. Any and all exceptions taken to these two sections on procedures are discussed in detail in the remainder of this portion of the report as well as the results generated.

DATA INPUT FORMAT

A deck of IBM cards in circuit symbol order containing 11,184 cards was furnished by EMEC. These cards represented the basic parts list to be used during this phase of the work. The cards were in the following format:

Data	Column
Circuit Symbol	10 - 37
Federal Stock Number (including alpha cog)	38 - 49
Part Name	55 - 62
Federal Stock Number Population	63 - 66

Data	Column
Numeric cog, Federal Stock Number	67
Source Code	71 - 72

It was necessary to transfer the above data to another card format called a data card since more information was required for provisioning calculations. The data card format used was as follows:

Data	Column
Code Number	1 - 4
Federal Stock Number	5 - 17
Circuit Symbol	18 - 30
Name	31 - 38
Source Code	39 - 40
Federal Stock Number Population	41 - 43
Essentiality Code	44
Blank	45 - 47
Cube	48 - 55 (decimal located in column 50)
Weight	56 - 64 (decimal assumed to be between ~~68 - 69)~~ 57-60)
Price	65 - 70 (decimal assumed to be between 68 - 69)
Replacement Rate	71 - 77 (decimal located in column 74)
APL Stock Quantity	78 - 80

The above data card format is different from that presented in Section IV due to the fact that the circuit symbol was required in order to generate the specified parts list print outs. The circuit symbol was compacted from the 28 columns used on the EMEC cards to the 13 columns as presented above and decimals were assumed in the weight and price fields so that all information could be placed on one data card, thereby simplifing the handling procedures.

The information contained on the EMEC card deck was transferred to the above data card format which completed the first 43 columns of the data card. The code number (columns 1-4) was assigned by Vitro and represents the circuit symbol sequence. The code number consists of an alpha symbol followed by three numerics. The code number was established to aid in sorting more efficiently the data cards in circuit symbol order. The code numbers run from A001 through L198, however, the code numbers A252, F158, F159, F160, and J910 were not used.

PARTS LIST

During the processing of the data cards some special cases were found to exist. There were four manufacturer's number on the EMEC cards which exceeded the 49th column and had the last character presented in column 50. These numbers were transposed to the data cards so that their last character was located in column 17. There was one each of the following manufacturer's numbers in this category:

CH05A3NC205K
CQ05A1VE105K
CQ22C155103K
RB16CEOR400F

There were 13 different manufacturer's numbers which exceeded column 49 on the EMEC cards and which, when transposed, one or two dashes were deleted from the number. This procedure was used to ensure that all the numbers could be recorded in the 13 columns set aside for this purpose. The list below shows the number as it appeared on the EMEC cards and number as punched in the data cards. Also shown under population is the total number of circuit symbols specified by the given number.

EMEC Cards	Vitro Data Cards	Population
10-4895/8DIA	104895/8DIA	7
2329F0045-10	2329F004510	1
2329F0045-11	2329F004511	1
2329F0045-12	2329F004512	1
404-115-0210	404115-0210	7
79-014-0620312	790140620312	2
C180-018-0500	C1800180500	12
C240-022-0690	C2400220690	16
MS91528-101B4	MS91528101B4	1
MS91528-102B2	MS91528102B2	1
MS91528-1D4B3	MS915281D4B3	1
MS91528-3K2B	MS915283K2B	9
NW6-6520-10B	NW66520-10B	2
		61

The above 13 manufacturer's numbers which appear 61 times in the parts list have only dashes deleted. All other Federal Stock Numbers and manufacturer's numbers are exact duplicates in the two card decks.

The dashes were also eliminated from the circuit symbol identification. For example, the EMEC card deck has circuit symbol 2A2A1C-211 which transposed to the data cards became 2A2A1C211. Columns 28, 29, and 30 were designated to contain the number appearing after the letter (part type reference) symbol (e.g., 211). It was noted that after the circuit symbols had been transposed to the data cards that in 22 cases truncation of the circuit symbols had occurred. These were as follows:

EMEC Card	Vitro Data Cards
12A3A2TB-1203	12A3A2TB203
16A1TB-1601	16A1TB601
16A1TB-1602	16A1TB602
18TB-1801	18TB801
22TB-2201	22TB201
22TB-2202	22TB202
22TB-2203	22TB203
22TB-2204	22TB204
22TB-2205	22TB205
22TB-2206	22TB206
22TB-2207	22TB207
22TB-2208	22TB208
22TB-2209	22TB209
23TB-2301	23TB301
23TB-2302	23TB302
23TB-2303	23TB303
23TB-2304	23TB304
23TB-2305	23TB305
24TB-2401	24TB401
24TB-2402	24TB402
24TB-2403	24TB403
24TB-2404	24TB404

An investigation of the circuit symbols within the AN/SPS-40 showed that no duplicates were generated due to the above truncation. Since these members were unique within the data cards and only 22 cases existed, no change was made to the card format but these circuit symbols were carried in the truncated form. A special condition was found to exist for two circuit symbols, 5A8T-3 and 5A8T-6, which each had four part numbers per circuit symbol. In order to process the data properly by the computer each of the circuit symbols were given terminal letters of A, B, C or D which produced the following data on the cards:

Circuit Symbol	Manufacturer's Part Number	Circuit Symbol	Manufacturer's Part Number
5A8T3A	4400C1180	5A8T6A	4400C1181
5A8T3B	4400B1184	5A8T6B	4400C1182
5A8T3C	4400B1179	5A8T6C	4400B1192
5A8T3D	4400B1190	5A8T6D	4400B1191

It may be of interest to note that there are four circuit symbols which legitimately terminate with a letter. These are 8A1A8MP3A, 8A1A8MP3B, 8A1A8MP5A, and 8A1A8MP5B.

Two complete parts lists are shown in Tables A-11 and A-12. Table A-11 is in Federal Stock Number order with the stock number repeated as many times as it is applied in the AN/SPS-40. The circuit symbol is shown for reference purposes. Along with the part name, Vitro assigned essentiality code, the EMEC assigned maintenance code, and the ESO assigned source code. Table A-12 shows the same information described above, but the table is in circuit symbol order which for this Phase II study represents the Section B of an allowance parts list. The tables identify 11,729 part applications within the AN/SPS-40 Radar. Of these part applications, 11,184 were identified by the deck of IBM cards received from ESO. These parts were used to determine the provisioning level of the 4 June 1965 Allowance Parts List. To the above parts EMEC made 545 changes which resulted in an adjusted parts list containing 11,729 part applications. The EMEC adjustments are identified in the parts lists of Table A-11 and Table A-12 by an asterisk in the first column. While the provisioning level calculation of the 4 June 1965 Allowance Parts List mentioned above was determined by deleting the entries with the asterisks, the calculation for determining the provisioning level of the 4 June 1965 Allowance Parts Lists as adjusted by EMEC and the stocks lists for the ship, supporting ship, and depot required using all the parts in the parts list; those with asterisks and those without.

Essentiality Codes

The essentiality code presented earlier is repeated below:

Code #1 Critical and installable by ship's force

Code #2 Critical and not installable by ship's force

Code #3 Noncritical and installable by ship's force

Code #4 Noncritical and not installable by ship's force

Even though codes #2 and #4 indicate that the item is not installable by the ship's force, it is considered installable at some point within the Navy organization. Items coded #2 and #4 will, therefore, be stocked by the depot but not by the ship or support ship. This approach was applied to the second phase of the contract as well as the first. Since this provisioning study started in May of 1964, the conditions specified for generating the stock lists have made the above four codes inadequate to fully describe the problem situation.

During this phase of the program two more sets of codes were generated so that the stock list development could properly consider the restraints placed upon it. The first set of codes, codes #5 and #6, are defined as follows:

Code #5 Critical but not to be considered for stocking

Code #6 Noncritical but not to be considered for stocking

Codes #5 and #6 would be assigned to items for the following reasons:

1. Item is to be fabricated such as produced from bar stock, gasket material, etc.
2. Item is to be replaced or repaired by using general stores such as hoses and cable harnesses.
3. Units which are to be repaired or replaced at lower levels such as antenna unit.
4. Items which are to be repaired or replaced outside of the Navy organization such as the parts within manufacturer repairable

assemblies.

5. Items which are replaced at a higher level such as a printed circuit board.

It was decided by EMEC that all items would be repaired within the Navy organization. Items which during Phase I had been considered as manufacturer repairable would in the future be repaired by a Navy module repair facility, therefore, category (4) above did not have application in the Phase II effort.

Table 19 lists the items assigned Codes #5 and #6 during this analysis. Table 19 is in Federal Stock Number-manufacturer's number order. The last column shows one of the above five numbers under the "Reason for Code Assignment" as explanation for the action taken. Some of the lines begin with an asterisk which indicates those parts which were added because of the EMEC's adjustment of the APL.

The final set of codes, codes #7 and #8, were added to allow for stocking aboard the support ship and carries the following definitions:

Code #7 Critical and stocked at support ship and depot but not ship,

Code #8 Non critical and stocked at support ship and depot but not ship.

Codes #7 and #8 were generated to consider shipboard installable items with low rates such that the item is being stocked primarily for protection or insurance, and at the same time has a high cost which would result in greatly increasing the stock inventory cost for items with little expectation of being required. The procedure has been to investigate every item which has a price of $50.00 or more to determine if codes #7 and #8 should be assigned.

TABLE 19. ITEMS DELETED FROM STOCK CONSIDERATION

Mfg. No./FSN	Circuit Symbol		Name	E.C.	Reason for E.C. Code Assignment
C147+2	5A34	MP 11	CLAMP	5	2
C147+3	5A34	MP 12	CLAMP	5	2
C147+4	5A34	MP 13	CLAMP	5	2
MS171495	4A 3	MP 16	ROLL PIN	5	1
MS171495	4A 3	MP 17	ROLL PIN	5	1
MS171495	4A 3	MP 18	ROLL PIN	5	1
MS171495	4A 3	MP 19	ROLL PIN	5	1
MS171495	4A 3	MP 20	ROLL PIN	5	1
MS171495	4A 3	MP 21	ROLL PIN	5	1
RFL176	11	MP 5	GASKET	5	1
RG157U		W 10	CABLE R	5	2
RG157U		W 11	CABLE R	5	2
RG157U		W 12	CABLE R	5	2
10+182	4A 3	MP 14	WEATHERS	5	1
104895/8DIA	5	MP 14	WEATHERS	5	1
104895/8DIA	7A 1	MP 3	WEATHERS	5	1
2329B0018	24A 1	L 13	INDUCTOR	5	1
2329B0018	24A 1	L 15	INDUCTOR	5	1
2329B0019	24A 1	L 7	INDUCTOR	5	1
2329B0019	24A 1	L 21	INDUCTOR	5	1
2329B0019+2	24A 1	L 9	INDUCTOR	5	1
2329B0019+2	24A 1	L 11	INDUCTOR	5	1
2329B0019+2	24A 1	L 17	INDUCTOR	5	1
2329B0019+2	24A 1	L 19	INDUCTOR	5	1
2329B0019+3	24A 2	L 7	INDUCTOR	5	1
2329B0019+3	24A 2	L 8	INDUCTOR	5	1
2329B0019+3	24A 2	L 12	INDUCTOR	5	1
2329B0019+3	24A 2	L 13	INDUCTOR	5	1
2329B0019+4	24A 2	L 6	INDUCTOR	5	1
2329B0019+4	24A 2	L 9	INDUCTOR	5	1
2329B0019+4	24A 2	L 11	INDUCTOR	5	1
2329B0019+4	24A 2	L 14	INDUCTOR	5	1
2329B0025	24A 1	MP 6	BAR	5	1
2329B0048	24A 1	MP 37	CUP	5	1
2329B0048	24A 1	MP 38	CUP	5	1
2329B0048	24A 1	MP 39	CUP	5	1
2329B0048	24A 1	MP 40	CUP	5	1
2329B0048	24A 2	MP 37	CUP	5	1
2329B0048	24A 2	MP 38	CUP	5	1
2329B0048	24A 2	MP 39	CUP	5	1
2329B0048	24A 2	MP 40	CUP	5	1
2329B0050	24A 1	L 6	INDUCTOR	5	1
2329B0050	24A 2	L 15	INDUCTOR	5	1

TABLE 19. ITEMS DELETED FROM STOCK CONSIDERATION (Continued)

Mfg. No./FSN	Circuit Symbol		Name	E.C.	Reason for E.C. Code Assignment
2329BC0099	24A 2	L 10	INDUCTOR	5	1
2329DC0083	5	W 1	CABLE AS	5	2
2329F0005	24		AMPL FLT	5	3
2329FC0094	5	W 2	WIRING	5	2
2333C0012	7A 2	MP 1	GASKET	5	1
2344C0042	5	W 5	CABLE AS	5	2
2344C0166	4	W 3	CABLE AS	5	2
2344C0166+2	4	W 4	CABLE AS	5	2
2344D0030	22A 9	E 1	PRINTED	5	5
2344D0144	4A 8	E 1	PNT CKT	5	5
2344D0144	6A 5	E 1	PNT CKT	5	5
2344F0144	4	W 1	CABLE AS	5	2
41889	23A 1	MP 17	HANDLE	6	2
41889	23A 1	MP 18	HANDLE	6	2
41890	1A 1	MP 4	HANDLE	6	2
41890	2A 1	MP 13	HANDLE	6	2
41890	3A 1	MP 2	HANDLE	6	2
41890	3A 1	MP 3	HANDLE	6	2
41890	3A 1	MP 4	HANDLE	6	2
41890	6	MP 17	HANDLE	6	2
41890	6	MP 18	HANDLE	6	2
41890	6	MP 19	HANDLE	6	2
41890	22	MP 15	HANDLE	6	2
41890	22	MP 16	HANDLE	6	2
4400B0106	16A 1	MP 2	GASKET	6	1
4400B0106	16A 1	MP 3	GASKET	6	1
4400B0106	16A 1	MP 4	GASKET	6	1
4400B0106	16A 1	MP 7	GASKET	6	1
4400B0436	2A 1	MP 7	GASKET	6	1
4400B0436	2A 1	MP 8	GASKET	6	1
4400B0436	4A 1	MP 7	GASKET	6	1
4400B0436	4A 1	MP 8	GASKET	6	1
4400B0436	4A 1	MP 9	GASKET	6	1
4400B0436	4A 1	MP 10	GASKET	6	1
4400B0436	23A 1	MP 2	GASKET	6	1
4400B0483	1	MP 7	STRAP	6	1
4400B0483	3	MP 7	STRAP	6	1
4400B0483	4	MP 45	STRAP	6	1
4400B0483	22	MP 5	STRAP	6	1
4400B1477	4	MP 46	GASKET	6	1
4401C0036	12A 3A1	MP 2	GASKET	6	1
4401C0055	12A 3A2	MP 4	GASKET	6	1
4569	8A 1	MP 22	CLIP	6	1
4569	8A 1	MP 23	CLIP	6	1
4569	8A 1	MP 24	CLIP	6	1
4569	8A 1	MP 25	CLIP	6	1
9Z5330B990414	1A 1	MP 1	GASKET	6	1

TABLE 19. ITEMS DELETED FROM STOCK CONSIDERATION (Continued)

Mfg. No./FSN	Circuit Symbol				Name	E.C.	Reason for E.C. Code Assignment
9N59208344705	8A	1	MP	16	CLIP	6	1
9N59208344705	8A	1	MP	17	CLIP	6	1
9N59208344705	8A	1	MP	18	CLIP	6	1
9N59208344705	8A	1	MP	19	CLIP	6	1
9N59208344705	8A	1	MP	20	CLIP	6	1
9N59208344705	8A	1	MP	21	CLIP	6	1
9N59997552918	4		MP	21	WEATHERS	6	1
2344F0165	4		W	2	CABLE AS	5	2
2630B0350+7	8A	1A8	MP	3B	GEAR BEV	5	1
2630B0350+8	8A	1A8	MP	3A	GEAR BEV	5	1
2630B0351+6	8A	1A8	MP	5B	GEAR BEV	5	1
2630B0351+7	8A	1A8	MP	5A	GEAR BEV	5	1
2630D0019	8A	1A3	E	1	BD PRINT	5	5
2630D0092	8A	1A6	E	1	BD PRINT	5	5
2630D0142	8A	1A5	E	1	BD PRINT	5	5
2630D0169	8A	1A4	E	1	BD PRINT	5	5
2630F0005	8A	1A1	E	1	BD PRINT	5	5
39915	7A	1	MP	5	PIN	5	1
39916	5		MP	1	GASKET	5	1
39916	5		MP	2	GASKET	5	1
39916	5		MP	3	GASKET	5	1
39916	5		MP	4	GASKET	5	1
39916	7A	1	MP	6	GASKET	5	1
39917	5		MP	5	GASKET	5	1
39917	5		MP	6	GASKET	5	1
39917	5		MP	7	GASKET	5	1
39917	5		MP	8	GASKET	5	1
39917	7A	1	MP	7	GASKET	5	1
41441+2	6		MP	1	GASKET	5	1
41888	5		MP	19	CATCH	5	2
41888	5		MP	20	CATCH	5	2
41888	5		MP	21	CATCH	5	2
41888	5		MP	22	CATCH	5	2
41888	6		MP	2	CATCH	5	2
41888	6		MP	3	CATCH	5	2
41888	6		MP	4	CATCH	5	2
41888	23		MP	14	CATCH	5	2
41888	23		MP	15	CATCH	5	2
41888	23		MP	16	CATCH	5	2
41890	5		MP	9	HANDLE	5	2
41890	5		MP	10	HANDLE	5	2
41890	5		MP	11	HANDLE	5	2
41890	5		MP	12	HANDLE	5	2
41890	7A	1	MP	4	HANDLE	5	2
4400B0106	9A	2	MP	1	GASKET	5	1
4400B0106	9A	2	MP	2	GASKET	5	1

TABLE 19. ITEMS DELETED FROM STOCK CONSIDERATION (Continued)

Mfg. No./FSN	Circuit Symbol	Name	E.C.	Reason for E.C. Code Assignment
4400B0106	9A 2 MP 3	GASKET	5	1
4400B0106	9A 2 MP 4	GASKET	5	1
4400B0106	9A 2 MP 5	GASKET	5	1
4400B0104	9A 2 MP 6	GASKET	5	1
4400B0253	5A 6 MP 5	COVER	5	1
4400B0253	5A 6 MP 6	COVER	5	1
4400B0253	5A 6 MP 9	CONDUCTO	5	2
4400B0253	5A 6 MP 10	CONDUCTO	5	2
4400B0253	5A 6 MP 11	CONDUCTO	5	2
4400B0253	5A 6 MP 12	CONDUCTO	5	2
4400B0261	5A 6 MP 13	CONDUCTO	5	2
4400B0261	5A 6 MP 14	CONDUCTO	5	2
4400B0261	5A 6 MP 15	CONDUCTO	5	2
4400B0261	5A 6 MP 16	CONDUCTO	5	2
4400B0475	24A 1 MP 3	COVER	5	1
4400B0475	24A 1 MP 4	COVER	5	1
33016	3A 1 MP 17	GASKET	4	1
33016	3A 1 MP 11	GASKET	6	1
33016	3A 1 MP 12	GASKET	4	1
33016	3A 1 MP 13	GASKET	4	1
33016	4 MP 9	GASKET	4	1
33016	4 MP 10	GASKET	4	1
33016	4 MP 11	GASKET	4	1
33016	4 MP 12	GASKET	4	1
33016	4 MP 8	GASKET	4	1
33016	4 MP 9	GASKET	4	1
33016	4 MP 10	GASKET	6	1
33016	22 MP 11	GASKET	4	1
33016	22 MP 12	GASKET	4	1
33016	23A 1 MP 3	GASKET	4	1
33016	23A 1 MP 4	GASKET	6	1
33016	23A 1 MP 5	GASKET	4	1
33016	23A 1 MP 6	GASKET	4	1
33017	2A 1 MP 7	GASKET	4	1
33017	2A 1 MP 18	GASKET	4	1
33017	2A 1 MP 19	GASKET	4	1
33017	3A 1 MP 8	GASKET	4	1
33017	3A 1 MP 9	GASKET	4	1
33017	3A 1 MP 10	GASKET	4	1
33017	4 MP 13	GASKET	6	1
33017	4 MP 14	GASKET	6	1
33017	4 MP 15	GASKET	4	1
33017	4 MP 16	GASKET	4	1
33017	4 MP 11	GASKET	4	1
33017	4 MP 12	GASKET	4	1
33017	4 MP 13	GASKET	4	1
33017	22 MP 13	GASKET	4	1

TABLE 19. ITEMS DELETED FROM STOCK CONSIDERATION (Continued)

Mfg. No./FSN	Circuit	Symbol	Name	E.C.	Reason for E.C. Code Assignment
30017	22	MP 14	GASKET	6	1
30017	23A 1	MP 7	GASKET	6	1
30017	23A 1	MP 8	GASKET	6	1
30017	23A 1	MP 9	GASKET	6	1
30017	23A 1	MP 10	GASKET	6	1
41441+2	22	MP 1	GASKET	6	1
*41888	1A 1	MP 12	CATCH	6	2
41888	3	MP 16	CATCH	6	2
41888	3	MP 17	CATCH	6	2
41888	3	MP 18	CATCH	6	2
41888	4	MP 41	CATCH	6	2
41888	4	MP 42	CATCH	6	2
41888	4	MP 43	CATCH	6	2
41888	4	MP 44	CATCH	6	2
*41888	7	MP 2	CATCH	6	2
41888	22	MP 3	CATCH	6	2
41888	22	MP 4	CATCH	6	2
41889	2A 1	MP 12	HANDLE	6	2
41889	4	MP 17	HANDLE	6	2
41889	4	MP 18	HANDLE.	6	2
41889	4	MP 19	HANDLE	6	2
41889	4	MP 20	HANDLE	6	2
41889	23A 1	MP 15	HANDLE	6	2
41889	23A 1	MP 16	HANDLE	6	2
2N4321788C311	18		PUMP COO	5	3
2N58407877485	17		HEAT EXC	5	3
2N58407984059	10		TANK LID	5	3
2F58408566037	12		ANT RADA	5	3
9N50600683858	5A 5	CR 1	1N277	5	5
2F590007552018	4	MP 69	WEATHERS	5	1
*2F590007552018	4	MP 70	WEATHERS	5	1
1N6145C808733		W 9	CABLE P	5	2
1N61451610909	11	W 12	CABLE	5	2
1N61451610909	11	W 13	CABLE	5	2
1N61451610909	11	W 14	CABLE	5	2
1N61451610909	11	W 15	CABLE	5	2
9Z61456552728	5A 8	W 7	CABLE	5	2
9Z61456552728	5A 8	W 8	CABLE	5	2
9Z61456552728	5A 8	W 9	CABLE	5	2
9Z61456552728	5A 8	W 10	CABLE	5	2
9Z61456552728	5A 8	W 11	CABLE	5	2
9Z61456552728	5A 8	W 12	CABLE	5	2
1N61457522415	3	W 7	CABLE	5	2
1N61457522415	3	W 8	CABLE	5	2
1N61457522415	3	W 9	CABLE	5	2
1N61457522415	3	W 10	CABLE	5	2
1N61457548159		W 7	CABLE R	5	2

TABLE 19. ITEMS DELETED FROM STOCK CONSIDERATION (Continued)

Mfg. No./FSN	Circuit Symbol	Name	E.C.	Reason for E.C. Code Assignment
[illegible]	[illegible]	CABLE [illegible]	[illegible]	2
[illegible]	[illegible] MP 1	WEATHERS	4	1
[illegible]	4 MP 20	WEATHERS	4	1
[illegible]/[illegible]	[illegible] MP 3	WEATHERS	4	1
[illegible]/[illegible]	[illegible] MP [illegible]	WEATHERS	4	1
[illegible]/[illegible]	[illegible] MP 26	WEATHERS	4	1
[illegible]/[illegible]	22 MP 17	WEATHERS	4	1
[illegible]/[illegible]	[illegible] MP 19	WEATHERS	4	1
[illegible]	[illegible] MP [illegible]	GASKET	4	1
[illegible]	[illegible] MP 18	GASKET	4	1
[illegible]	[illegible] MP 5	GASKET	4	1
[illegible]	[illegible] MP 5	GASKET	[illegible]	1
[illegible]	[illegible] MP 5	PIN	4	1
[illegible]	[illegible] MP 14	PIN	4	1
[illegible]	[illegible] MP 15	PIN	4	1
[illegible]	[illegible] MP [illegible]	PIN	4	1
[illegible]	[illegible] MP 4	PIN	4	1
[illegible]	[illegible] MP [illegible]	PIN	4	1
[illegible]	[illegible] MP 6	PIN	4	1
[illegible]	4 MP [illegible]	PIN	4	1
[illegible]	4 MP 8	PIN	4	1
[illegible]	4 MP 14	PIN	4	1
[illegible]	4 MP 15	PIN	4	1
[illegible]	6 MP 16	PIN	4	1
[illegible]	[illegible] MP [illegible]	PIN	4	1
[illegible]	[illegible] MP [illegible]	PIN	4	1
[illegible]	[illegible] MP [illegible]	PIN	4	1
[illegible]	[illegible] MP 12	PIN	4	1
[illegible]	[illegible] MP [illegible]	PIN	4	1
[illegible]	[illegible] MP 14	PIN	4	1
[illegible]	[illegible] MP 4	GASKET	4	1
[illegible]	[illegible] MP 16	GASKET	4	1
[illegible]	[illegible] MP 3	COVER	[illegible]	1
[illegible]	[illegible] MP 4	COVER	[illegible]	1
[illegible]	[illegible] MP 6	COVER	[illegible]	1
[illegible]	[illegible] MP [illegible]	COVER	[illegible]	1
[illegible]	[illegible] MP 12	COVER	[illegible]	1
[illegible]	[illegible] MP 13	COVER	[illegible]	1
[illegible]	[illegible] MP [illegible]	STRAP	[illegible]	1
[illegible]	[illegible] MP 20	STRAP	[illegible]	1
[illegible]	[illegible] MP 5	STRAP	[illegible]	1
[illegible]	[illegible] MP [illegible]	STRAP	[illegible]	1
[illegible]	[illegible] MP [illegible]	GASKET	[illegible]	1
[illegible]	[illegible] MP [illegible]	BAR	[illegible]	1
[illegible]	[illegible] MP [illegible]	BAR	[illegible]	1
[illegible]	[illegible] MP 14	BAR	[illegible]	1
[illegible]	[illegible] MP [illegible]	BAR	[illegible]	1

TABLE 19. ITEMS DELETED FROM STOCK CONSIDERATION (Continued)

Mfg. No./FSN	Circuit Symbol		Name	E.C.	Reason for E.C. Code Assignment
4400B0601	5A12	MP 25	CAP	5	1
4400B0606	5A12	MP 4	COVER	5	1
4400B0606	5A12	MP 9	COVER	5	1
4400B0606	5A12	MP 13	COVER	5	1
4400B0606	5A12	MP 17	COVER	5	1
4400B0606	5A12	MP 20	COVER	5	1
4400B0612	5A12	MP 1	COVER	5	1
4400B0613	5A12	MP 2	INDUCTOR	5	1
4400B0714	6A 2	Z 12	STRAP	5	1
4400B0715	6A 2	Z 3	STRAP	5	1
4400B0716	6A 2	Z 6	STRAP	5	1
4400B0717	6A 2	Z 9	STRAP	5	1
4400B0722	6A 2	Z 15	STRAP	5	1
4400B1237	9A 2	MP 7	GASKET	5	1
4400B1238	9A 2	MP 8	GASKET	5	1
4400B2056	4A 2	MP 17	GASKET	5	1
4400C0193	5A 4	E 7	BOARD	5	5
4400C0199	24A 1	MP 19	SPACER	5	2
4400C0199	24A 1	MP 20	SPACER	5	2
4400C0199	24A 1	MP 21	SPACER	5	2
4400C0199	24A 1	MP 22	SPACER	5	2
4400C0199	24A 1	MP 23	SPACER	5	2
4400C0199	24A 1	MP 24	SPACER	5	2
4400C0199	24A 1	MP 45	SPACER	5	2
4400C0199	24A 1	MP 46	SPACER	5	2
4400C0199	24A 1	MP 47	SPACER	5	2
4400C0199	24A 1	MP 48	SPACER	5	2
4400C0199	24A 1	MP 49	SPACER	5	2
4400C0199	24A 1	MP 50	SPACER	5	2
4400C0199	24A 2	MP 19	SPACER	5	2
4400C0199	24A 2	MP 20	SPACER	5	2
4400C0199	24A 2	MP 21	SPACER	5	2
4400C0199	24A 2	MP 22	SPACER	5	2
4400C0199	24A 2	MP 23	SPACER	5	2
4400C0199	24A 2	MP 24	SPACER	5	2
4400C0199	24A 2	MP 45	SPACER	5	2
4400C0199	24A 2	MP 46	SPACER	5	2
4400C0199	24A 2	MP 47	SPACER	5	2
4400C0199	24A 2	MP 48	SPACER	5	2
4400C0199	24A 2	MP 49	SPACER	5	2

TABLE 19. ITEMS DELETED FROM STOCK CONSIDERATION (Continued)

Mfg. No./FSN	Circuit Symbol			Name	E.C.	Reason for E.C. Code Assignment
4400D0960	5A18	E	1	BD PNT C	5	5
4400D0960	5A19	E	1	BD PNT C	5	5
4400D0960	5A20	E	1	BD PNT C	5	5
4400D0960	5A21	E	1	BD PNT C	5	5
4400D0960	5A22	E	1	BD PNT C	5	5
4400D0960	5A23	E	1	BD PNT C	5	5
4400D0960	5A24	E	1	BD PNT C	5	5
4400D0997	22A 2	E	1	BD PRINT	5	5
4400D1030	22A 3	E	1	BD PRINT	5	5
4400D1043	22A 4	E	1	BD PRINT	5	5
4400D1057	5A29	E	1	BD PNT C	5	5
4400D1079	5A30	E	1	BD PNT C	5	5
4400D1124	23A 6	E	5	BD PRINT	5	5
4400D1151	5A48	E	1	BD PNT C	5	5
4400D1247	6A 4	W	1	CABLE	5	2
4400D1257	9			DEHYDRAT	5	3
4400D1716	6A 3A1	W	1	CABLE	5	2
4400D1963	5A58	E	1	BD PNT C	5	5
4400F0029	9			RANGE IN	5	3
4400F0032	8	A	1	CHASSIS	5	1
4400F0305	7			RADAR SE	5	3
4400F0399	1			PWR CONT	5	3
4400F0522	2			MOD PWR	5	3
4400F0524	2	W	1	CABLE	5	2
4400F0525	2	W	2	CABLE	5	2
4400F0526	2	W	3	CABLE	5	2
4400F0901	3			RADAR MO	5	3
4400F0878	5			RECEIVER	5	3
4400F0916	6A 2	W	1	CABLE	5	2
4400F1210	22			LV PWR S	5	3
4400F1289	3	W	1	CABLE	5	2
4400F1291	3	W	2	CABLE	5	2
4400F1293	3	W	3	CABLE	5	2
4400F1295	3	W	4	CABLE	5	2
4400F1299	3	W	6	CABLE	5	2
4400F1347	16			IND MON	5	3
4400F1364	21			PURIFIER	5	3
4400F1405	4A 3	W	1	INNER CO	5	1
4400F1475	4			AMPLIFIE	5	3
4400F1560	23			MOD RADA	5	3
4400F1770	4A 2	W	2	OUTER CO	5	1
4400F1824	4A 3	W	2	OUTER CO	5	1
4400F1900	5			AMPLIFIE	5	3
*4400F1990	4	W	5	CABLE	5	2
*4400F1991	4	W	6	CABLE	5	2
4401F0022	12	A	3	PEDESTAL	5	3
482512	5	MP	13	TUNING	5	1

TABLE 19. ITEMS DELETED FROM STOCK CONSIDERATION (Continued)

Mfg. No./FSN	Circuit Symbol		Name	E.C.	Reason for E.C. Code Assignment
80104-14	2A 2A1	MP 1	BOARD	5	5
80104+14	2A 2A1	MP 2	BOARD	5	5
80104+14	2A 2A1	MP 3	BOARD	5	5
80104-14	2A 2A1	MP 4	BOARD	5	5
80104+14	2A 2A1	MP 5	BOARD	5	5
80104+14	2A 2A1	MP 6	BOARD	5	5
80104-30	2A 2A2	MP 1	BOARD	5	5
2N4310073 3573	10		COMPRESS	5	3
44000199	24A 2	MP 50	SPACER	5	2
44000199+2	24A 1	MP 13	SPACER	5	2
44000199+2	24A 1	MP 14	SPACER	5	2
44000199+2	24A 1	MP [illegible]	SPACER	5	2
44000199+2	24A 1	MP 16	SPACER	5	2
44000199+2	24A 1	MP 17	SPACER	5	2
44000199+2	24A 1	MP 18	SPACER	5	2
44000199+2	24A 2	MP 13	SPACER	5	2
44000199+2	24A 2	MP 14	SPACER	5	2
44000199+2	24A 2	MP 15	SPACER	5	2
44000199+2	24A 2	MP 16	SPACER	5	2
44000199+2	24A 2	MP 17	SPACER	5	2
44000199+2	24A 2	MP 18	SPACER	5	2
44000251	5A 6	MP 1	BLOCK	5	1
44000251	5A 6	MP 2	BLOCK	5	1
44000470	24A 5	MP 3	BRACKET	5	1
44000602	5A12	MP 6	INDUCTOR	5	1
44000612	5A12	MP 15	INDUCTOR	5	1
44000613	5A12	MP 10	INDUCTOR	5	1
44000613	5A12	MP 22	INDUCTOR	5	1
44000614	5A12	MP 18	INDUCTOR	5	1
44000615	5A12	MP 16	INDUCTOR	5	1
44001255	9A 2	MP 9	GASKET	5	1
44001265	9	W 1	CABLE	5	2
44001265+2	9	W 2	CABLE	5	2
44001266	9	W 3	CABLE	5	2
44001267	9	W 4	CABLE	5	2
44001267+2	9	W 5	CABLE	5	2
44001268	9	W 6	CABLE	5	2
44001270	9	W 7	CABLE	5	2
[illegible]	5A 6	MP 3	BLOCK	5	1
[illegible]	5A 6	MP 4	BLOCK	5	1
44002076	5A 6	MP 7	COVER	5	1
44002076	5A 6	MP 8	COVER	5	1
[illegible]		W 1	CABLE AS	5	2
44002119		W 2	CABLE AS	5	2
[illegible]		W 3	CABLE AS	5	2

TABLE 19. ITEMS DELETED FROM STOCK CONSIDERATION (Continued)

Mfg. No./FSN	Circuit Symbol	Name	E.C.	Reason for E.C. Code Assignment
4400C2120	W 4	CABLE AS	5	2
4400C2120	W 5	CABLE AS	5	2
4400C2120	W 6	CABLE AS	5	2
4400D0102	9 A 2	JUNCTION	5	1
4400D0165	3A 4 E 1	BD PRINT	5	5
4400D0165	3A 5 E 1	BD PRINT	5	5
4400D0165	23A 2 E 1	BD PRINT	5	5
4400D0165	23A 3 E 1	BD PRINT	5	5
4400D0183	3A 2 E 1	PRINT CK	5	5
4400D0195	5A13 E 3	BD PNT C	5	5
4400D0197	5A13 E 4	BD PNT C	5	5
4400D0213	3A 7 E 1	PNT CKT	5	5
4400D0284	5A39 E 3	BD PNT C	5	5
4400D0904+4	5 W 3	CABLE AS	5	2
4400D0904+5	5 W 4	CABLE AS	5	2
4400D0960	5A15 E 1	BD PNT C	5	5
4400D0960	5A16 E 1	BD PNT C	5	5
4400D0960	5A17 E 1	BD PNT C	5	5

Table 20 lists the 43 parts which were assigned code 7. In this particular analysis there were no parts assigned code 8. Table 20 in Federal Stock Number-manufacturer's number order with each entry accompanied by circuit symbol, name, item cost, and the mean time between usage in years. In other words, for the first entry, IN3040-444-9778 it is anticipated that there will be one of this type of part required per equipment every 844 years. For this low expected usage it does not appear to be practical to stock this $175.00 item aboard each ship.

Maintenance Policy

The maintenance policy stipulated by EMEC for the AN/SPS-40 Radar is as follows:

1. These assemblies are not supplied as complete assemblies aboard ship as spares. Certain bits and pieces have been furnished that ships force can repair. Assemblies may be turned in for repair if parts are not supplied.

   In general, these assemblies will be repaired by shore repair.

Unit 21	Unit 2
Unit 11	Unit 4A2
Unit 12	Unit 4A3
Unit 9	Unit 8
Unit 16	Unit 14
Unit 6A2	Unit 17
Unit 6A3	Unit 7
Unit 18	Unit 14
Unit 1	

2. These modules and assemblies are not supplied complete as assemblies or modules. No bits and pieces have been supplied. They must be turned in for repair.

Unit 2A2	Unit 20
Unit 10	Unit 5A37
Unit 19	Unit 5A47
Unit 15	

Table 20. Code 7 Items

Federal Stock Number	Circuit Symbol	Name	Cost	Mean Time Between Usage in Years
1N3040-444-9778	12A3A2 MP-1	GEAR	$175.00	844
2N4320-620-7199	18 U-1	PUMP	1,140.00	8
2N4440-837-8047	9 A1	DEHYDRAT	300.00	3,800
1N4820-444-9775	9 MP-1	VALVE	116.00	31
1N4820-444-9776	9 MP-4	VALVE	170.00	31
2N5840-733-5283	11 AT-4	LOAD ASY	250.00	26
2N5840-787-3709	5 A25	DELAY LINE	1,525.00	19
2N5840-798-4948	5 A14	XTAL FLT	4,450.00	2
2N5840-966-7707	24 A1	LP FIL+A	700.00	9
1N5840-966-7708	24 A2	HP FIL A	700.00	7
1N5840-987-1496	11 W-8	HYBRID T	985.00	24
9N5905-713-5296	12A3A2 R-1	RESISTOR	111.00	43
9N5905-898-9305	23 R-3	RESISTOR	183.83	90
9N5910-789-5241	23 C-48	CAPACITOR	112.50	220
2N5915-076-0129	24 A4	HP FILTE	900.00	22
2N5915-076-2145	24 A3	LP FILTE	900.00	94

Table 20. Code 7 Items Continued

Federal Stock Number	Circuit Symbol	Name	Cost	Mean Time Between Usage in Years
1N5915-713-5365	3 Z-2	NETWORK	$162.00	37
2N5915-713-5366	3 Z-3	PUL FOR	1,190.00	33
1N5915-812-0126	5 A11	280+330	269.00	32
2N5915-838-1891	5 A54	120MC	154.00	32
1N5915-860-0861	5 A56	HI PASS	119.00	88
9N5930-779-2484	13	ANT SAFE	47.50	238
1N5935-020-5791	4 MP-8	CONNECTOR	75.00	132
9N5935-733-5274	2 J-1	CONNECTOR	103.00	196
1N5935-956-3036	P-5	CONNECTOR	104.00	178
9N5945-715-2353	4 K-9	RELAY	124.00	31
9N5950-020-2782	22 T-4	TRANSFORMER	125.00	33
9N5950-620-7212	23 T-5	TRANSFORMER	180.00	33
9N5950-731-4422	23 T-6	TRANSFORMER	309.00	33
9N5950-732-8524	4 T-1	TRANSFORMER	249.00	33
9N5950-838-1908	23 L-6	REACTOR	155.00	42
9N5950-838-1909	23 L-4	REACTOR	155.00	42
9N5950-838-1911	23 L-1	REACTOR	155.00	42

Table 20. Code 7 Items Continued

Federal Stock Number	Circuit Symbol	Name	Cost	Mean Time Between Usage in Years
9N5950-838-1912	23 L-3	REACTOR	$155.00	42
9N5950-838-1930	22 T-3	TRANSFORMER	206.00	33
9N5950-838-4369	23 T-7	TRANSFORMER	309.00	33
1N5985-733-5289	11 W-10	BI DIR	250.00	43
1N5985-733-5290	11 W-11	COUPLER	250.00	43
2N6625-860-0862	5 A57	GEN AND	250.00	64
1N6645-020-2787	9A1 MP-7	TIMER ME	144.00	64
4400 F 1883	4A6	DRIVE AS	1,400.00	114
4400 F 1884	4A5	DRIVE AS	1,400.00	114
4400 F 1884-2	4A7	DRIVE AS	1,400.00	114

3. These modules supplied as complete units. No bits and pieces, except tubes, have been supplied for these modules. Modules will be turned in for repair.

3A2	5A14	5A39	22A2
3A3	5A15	5A40	22A3
3A4	5A24	5A42	22A4
3A5	5A25	5A43	22A5
3A7	5A26	5A45	22A6
3A9	5A27	5A46	22A7
5A3	5A28	5A48	22A8
5A4	5A29	5A49	23A2
5A5	5A30	5A50	23A3
5A6	5A31	5A52	23A6
5A7	5A32	5A53	23A7
5A9	5A33	5A54	24A1
5A10	5A34	5A55	24A2
5A11	5A35	5A56	24A3
5A12	5A36	5A57	24A4
5A13	5A38	5A58	24A5

4. These modules are not supplied as complete units. Certain bits and pieces are furnished. These modules will be repaired aboard ship; however, they may be turned in for Shore Repair.

5A8	4A8	22A9
5A44	6A5	23A5

5. These two assemblies supplied as complete assemblies. Not bits and pieces supplied.

6A4
6A3A1

Table 21 presents a summary of the various item categories generated through the maintenance policy stipulated by EMEC for the AN/SPS-40 Radar, the associated essentiality codes assigned, and the corresponding locations which would be a candidate for stocking items within the category. Two numbers are shown in the essentiality code. The first is used if the item

TABLE 21 SUMMARY OF ITEM ESSENTIALITY CODE, STOCK LOCATIONS AND RATES

ITEM NO.	ITEM DESCRIPTION	Assigned Essentiality Code	Stock Locations: Ship/ Equip. Site	Stock Locations: Support Supply Ship	Stock Locations: Depot	Stock Locations: Not In System	Type Of Rate
1.	Units to be repaired/replaced at lower breakdown level.	5/6				X	-
2.	Assemblies NOT to be repaired in any manner by ship but are shipboard installable.	1/3	X	X	X		λ F
3.	Assemblies NOT to be repaired by ship except for plug-in and/or selected parts but are shipboard installable.	1/3	X	X	X		λ F
4.	Assemblies NOT to be replaced or installed by ship but repairable at another location.	2/4			X		λ M
5.	Assemblies NOT to be replaced or installed by ship and NOT repairable.	2/4			X		λ F
6.	Assemblies repairable by ship.	2/4			X		λ M
7.	Repair parts installable by ship in 1 and 6 above.	1/3	X	X	X		λ R
8.	Plug-in and selected parts installable by ship in 3 above.	1/3	X	X	X		λ R
9.	Parts within assemblies to be replaced by Navy Module Repair Facility Only.	2/4			X		λ R
10.	Parts within assemblies to be replaced by Manufacturer or organization NOT within the Navy.	5/6				X	-
11.	Items to be installed by shipyard/support ship only.	2/4			X		λ R
12.	Items to be fabricated.	5/6				X	-
13.	Items to be replaced from general stores.	5/6				X	-
14.	Parts with low expected usage, high cost, and installable by ship.	7/8		X	X		λ R
15.	Assemblies with low expected usage, high cost, and installable by ship.	7/8		X	X		λ F

is critical the second is used if the item is noncritical. The number of the item to be stocked is determined by the computer using the cumulative Poisson probability function. The purpose of the essentiality codes is to properly direct the computer concerning the appropriate stock locations of the items within the radar.

Inherent in Table 21 is the equipment top down break down of units, assemblies, and parts. The term "item" is meant to include any of the three breakdowns of units, assemblies, or parts as applicable.

Rates

The procedure derived during this study requires as one of the inputs the rate at which the item will be used. The manner in which the item is to be maintained influences the choice of rate. There are three kinds of rates being used for this provisioning procedure for the AN/SPS-40 Radar. These are failure rate, replacement rate, and mortality rate.

The definitions of these terms as applied to this study are as follows:

1. Replacement rate, λ_R, is the rate at which items are consumed by an equipment. Mathematically the replacement rate is determined as

$$\lambda_R = \frac{\text{No. of Item Replacements}}{\text{Item Population x Operating Time}}$$

which produces an item replacement rate on the basis of item operating time. Replacement rates have been determined by Vitro from Navy experience for most of the items in the AN/SPS-40 Radar.

2. Failure rate, λ_F, is the rate at which items cause an equipment to malfunction. Mathematically the failure rate is determined as

$$\lambda_F = \frac{\text{No. of Items Causing Equipment Malfunction}}{\text{Item Population x Operating Time}}$$

which produces an item failure rate on the basis of item operating time. For example, during a given period of equipment operation there may be 10 equipment malfunctions which require 30 parts to be replaced in order to keep the equipment in operation. This

example indicates that 10 component failures, otherwise known as primary failures, directly caused equipment malfunctions. The items which were responsible for producing the malfunction condition are charged with primary failures and from these primary failures the failure rate is calculated. The remaining 20 parts, secondary failures, which were required are failed parts but are in a failed condition due to the primary failure. In other words, if the primary failure had not occurred there would have been no need for replacing the remaining 20 parts. Through analysis of Navy equipment malfunctions, Vitro has produced failure rates for most of the items in the AN/SPS-40 Radar.

3. Mortality rate, λ_M, is the rate at which repairable assemblies are retired from service. The assemblies are considered as retirable when it is no longer feasible to make repairs but to replace it with a new assembly. The decision to replace with a new assembly rather than repair would probably be based on economic considerations. Such a situation occurs when it is cheaper to replace than to repair. No collection of mortality rates exist, therefore the mortality rates used were determined through engineering judgement and a knowledge of the item's replacement rate and failure rate. The relationship of the three rates discussed above is as follows:

$$\lambda_M \subset \lambda_F \subset \lambda_R$$

where

λ_M = mortality rate

λ_F = failure rate

λ_R = replacement

$\subset$ = subset of

Table 21 shows the application of three types of rates for the various categories of parts established for this program. As illustrated by the table the selection of failure rate was made for assemblies which were not to be repaired by the ship. While it is true that the malfunctioning assembly is likely to have several failed parts within it, it is not likely that primary and secondary failures will occur between assemblies. Therefore, assembly usage is described by primary failures which is accounted for by applying the failure rate.

For those assemblies which would be repaired, the assembly would be required from stock only when it was no longer feasible to make repairs. For these repairable assemblies the mortality rate was used to calculate stock quantities.

The repair parts, regardless of who is to accomplish the repair action, are subject to the primary and secondary failure phenomenon and, therefore must be calculated on the basis of replacement rates.

The assignment of rates as well as the essentiality codes has involved an underlying assumption concerning the pipeline configuration. Figure 14 presents the pipeline configuration used in this analysis. A point of major importance concerning the diagram is that the ship does not deal directly with the Navy Module Maintenance Facility, but all such actions are processed through the depot. Deviations from this procedure would necessitate changes in the assembly stocking procedure for those assemblies being repaired by the facility.

<u>Computer Program Changes</u>

Because a more detailed and refined output is required for the Phase II effort, it was necessary to adjust the support ship stocking procedure such

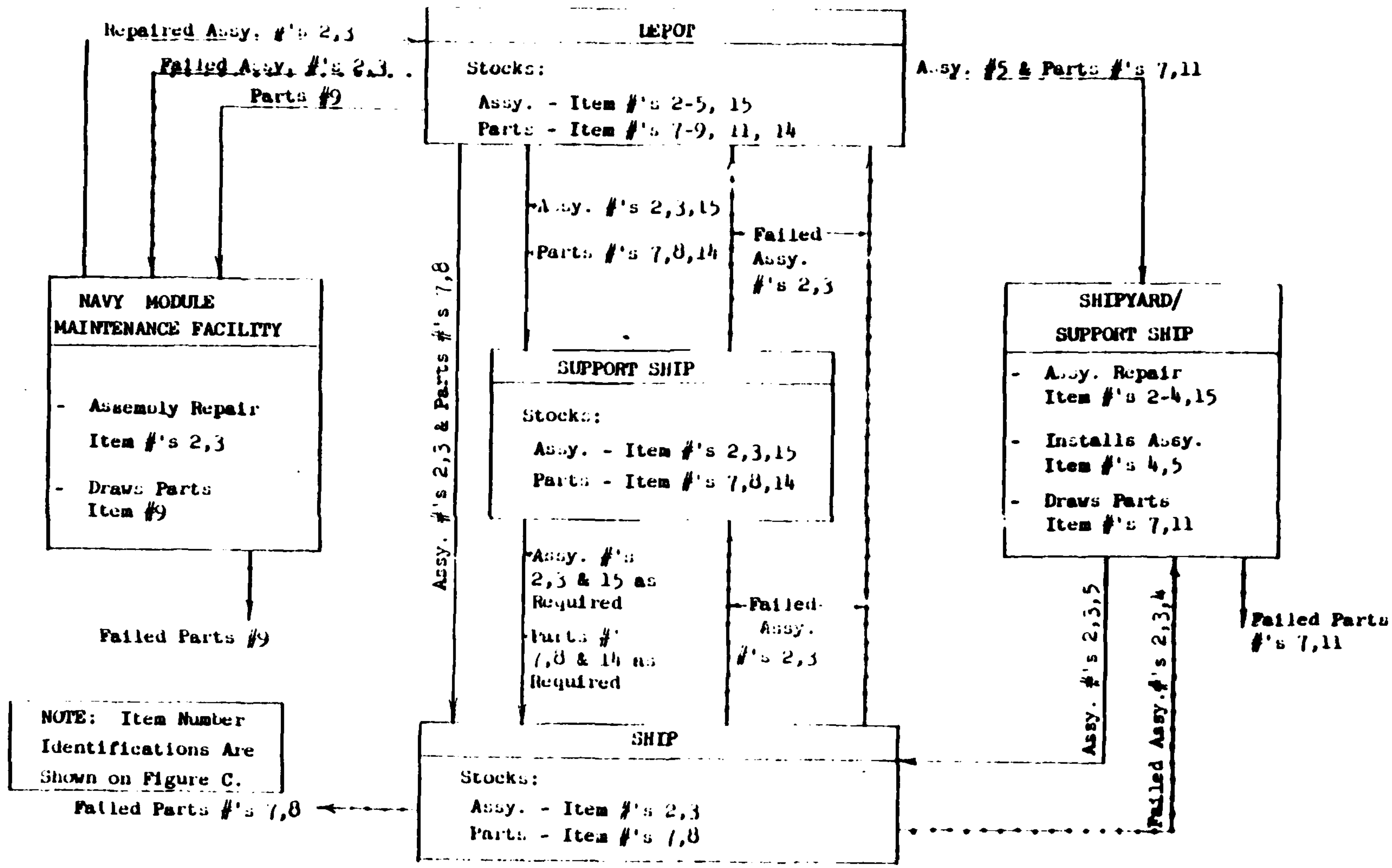

Figure 14. Pipeline Configuration

that it would accept items for stocking which were not considered for ship stocking. The items which fall into this category have been assigned essentiality codes #7 and #8 which is the means by which the computer recognizes this situation. Details of essentiality codes #7 and #8 and the specific items which have been assigned these codes have been discussed previously under the subheading of Essentiality Codes. The remaining alterations made to the computer program all concern the output format. These alterations are as follows:

1. The stock lists for ship, support ship, and depot are in stock number order. The Phase I stock lists were in primary order by essentiality and secondary order by Federal Stock Number. The Phase II print outs are in primary order by Federal Stock Number and secondary order by essentiality code.
2. The Phase II stock lists have the Federal Stock Numbers separated by two dashes which occur between the 6th and 7th digits and the 9th and 10th digits; e.g., 9N5960-476-3934. This procedure not only complies with convention but makes the federal stock numbers much easier to read than running all the digits together.
3. The order of the data columns and their titles have been changed to produce a more usable and easier to understand stock list. These changes are presented later in this report as each stock list is discussed in detail.

Section X

Results

GENERATED STOCK LISTS (Facility Repair)

The Electronics Maintenance Engineering Center's parts list for the AN/SPS-40 Radar was used to produce the three stock lists for the ship, support ship, and depot. The adjusted parts list contain a total 11,729 parts which is the number of circuit symbols within the radar. Table A-11 presented earlier gives a complete listing of the items considered. Table A-13 represents the equipment stock list for a ship for the AN/SPS-40 Radar. Table A-13 corresponds to a Section C of an Allowance Parts List. The equipment stock list was determined at the 90% provisioning level for a 90-day stock period and then one spare was assigned to each initial item which had not been allowed a spare.

The format of Table A-13 has been altered from those stock lists generated during Phase 1. The order and titles used in Table A-13 are as follows:

Titles	Remarks
FSN/MANUFACTURER's NUMBER	The first entry presents the Federal Stock Number. If no Federal Stock Number was assigned, the manufacturer's number was used.
ITEM NAME	An abbreviated name for the entry is used where only eight spaces are available.
ALLOWED QUANTITY	The number of items which are to be allowed as on-board stock.

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Titles	Remarks
EC	Essentiality Code assigned.
POPULATION/EQUIPMENT	The number of times the part type is contained within the radar under the assigned essentiality code.
PRICE/QUANTITY	The cost of the number of on-board stock items; e.g. if there are 3 items of a particular type allowed as on-board stock (entry #4) and these items cost $.10 each, then the Price/Quantity entry would show $.30 as the combined price of the 3 items.
WEIGHT/QUANTITY	The combined weight of the number of items allowed on-board in pounds.
CUBE/QUANTITY	The combined volume of the number of items allowed on-board in cubic feet.
RATE	The rate shown is the rate assigned per one item for a 90-day period.
NUMBER	This entry contains the code number assigned to the entry so th[illegible] it may be traced through the calculati[illegible] at various provisioning levels if hand adjustment of the stock is deemed necessary. The calculations are presented in Table A-17.

Table A-13 is presented in Federal Stock Number and manufacturer's number order. When a part number has been assigned more than one code number there are multiple entries in the table. Table A-13 recommends for 94.9% provisioning level that a total of 2,095 items (depth) be allowed as on-board stock which represents a range of 1480 part types. The equipment stock list has a total cost of $89,957.27, a weight of 527 pounds, and a volume of 35.5 cubic feet. Of the 2,095 items stocked 263 were critical items assigned one spare. The 90% provisioning level, therefore, had a depth of 1832 with a value of $89,413.98.

Table 22 shows the provisioning level versus stock period. Figure 15 is a graphical representation of Table 22. Table 23 is the equipment constraints of cost, weight, and cube versus provisioning level which is shown in graphical form in figure 16. The intent and application of the above tables and figures are the same as discussed in Phase I.

The second stock list generated under Phase II is for the support ship and is presented in Table A-14. The support ship stock list was determined for a support ship which supplies six equipments or ships at a 95% provisioning level for a six month stock period. Table A-14 is in the same format as Table A-13 with the one exception that the rate shown in entry #9 is the rate for six items for a six month stock period. Table A-14 recommends that a total of 757 items (depth) be allowed as on-board stock which represents a range of 522 part types. The support ship stock list has a total cost of $119,693.62, a weight of 565 pounds, and a volume of 46.7 cubic feet. Table 24 presents the support ship constraints of cost, weight, and cube which are presented graphically in figure 17.

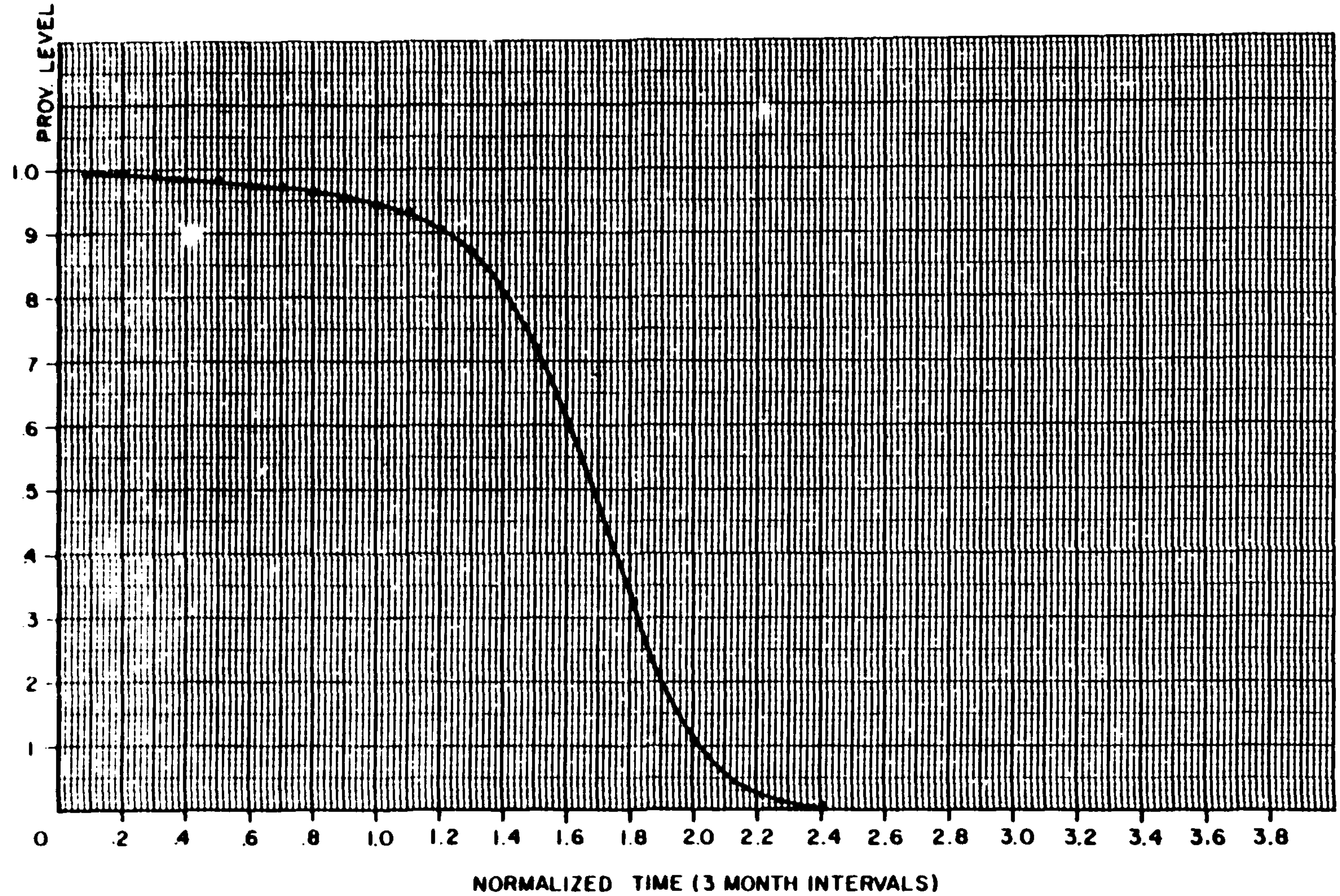


Figure 15. Equipment Stock Period Variation Graph - Facility Repair

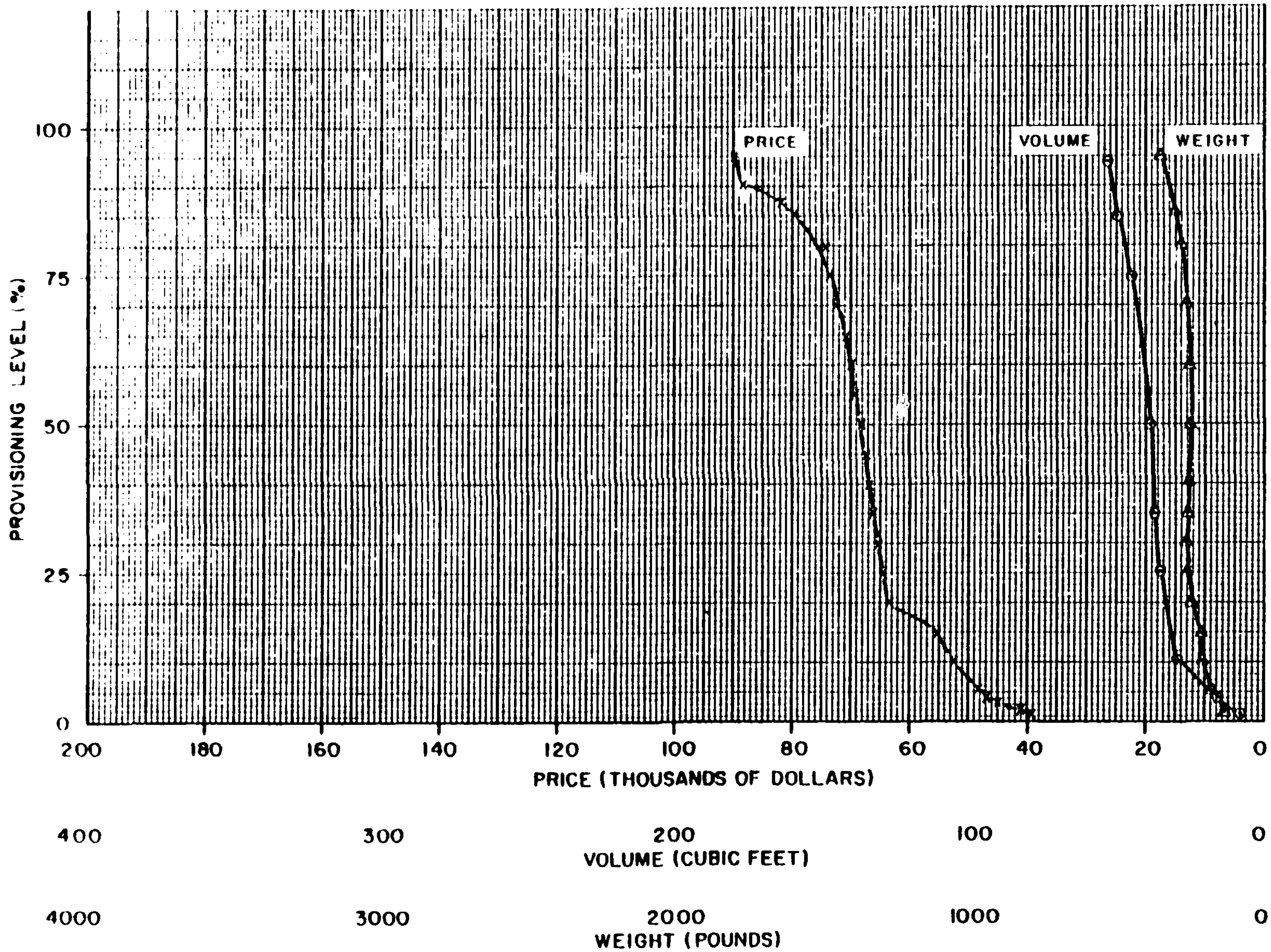


Figure 16. Equipment Stock Constraints Graph - Facility Repair

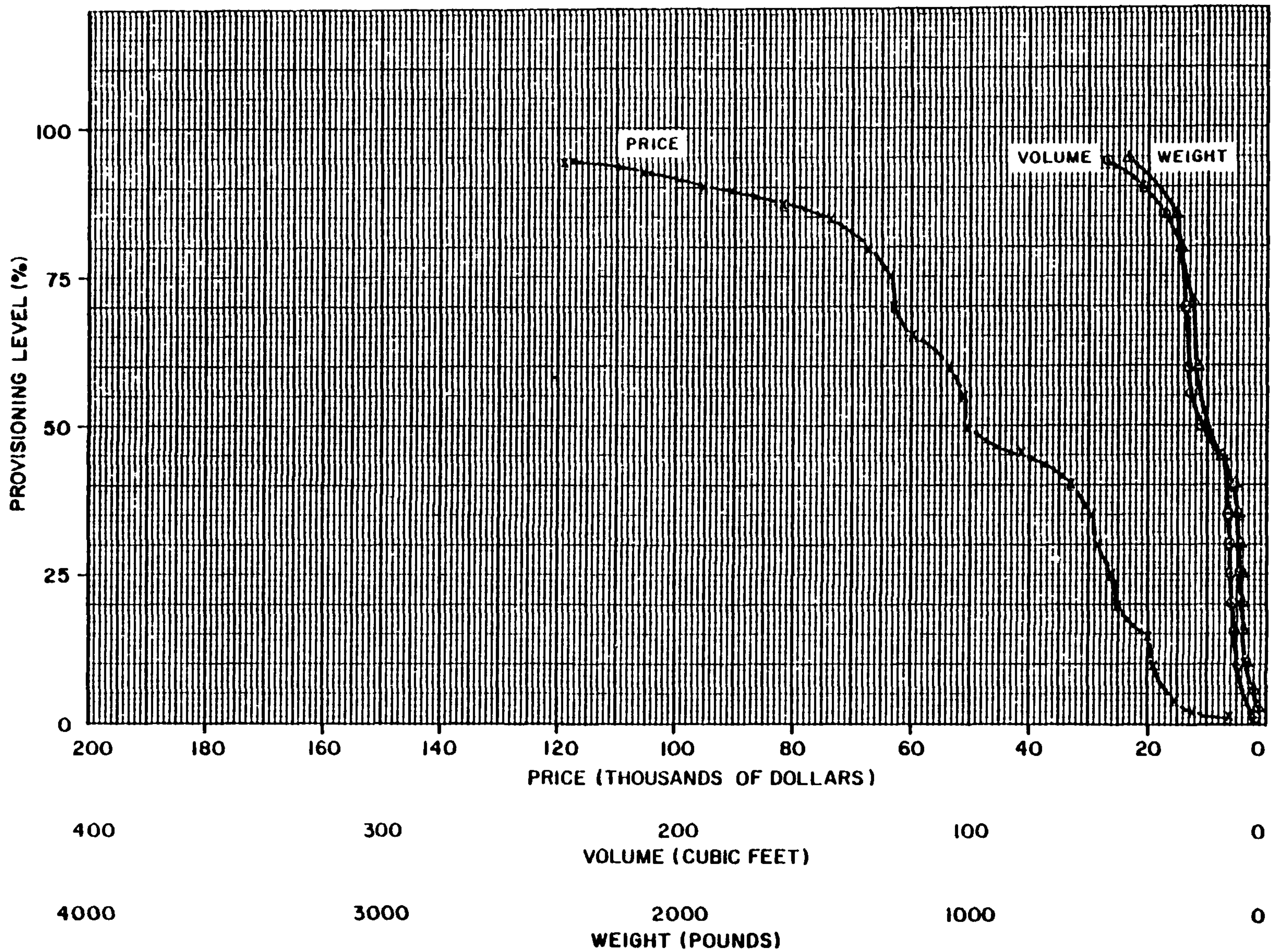


Figure 17. Support Ship Stock Constraints Graph - Facility Repair

TABLE 22. EQUIPMENT STOCK PERIOD VARIATION - FACILITY REPAIR

Provisioning Level	Normalized Time (90 Days = 1.00)
0.99810	0.08000
0.99785	0.09000
0.99759	0.10000
0.99481	0.20000
0.99162	0.30000
0.98798	0.40000
0.98384	0.50000
0.97912	0.60000
0.97371	0.70000
0.96735	0.80000
0.95953	0.90000
0.94909	1.00000
0.94652	1.02000
0.94373	1.04000
0.94069	1.06000
0.93739	1.08000
0.93377	1.10000
0.92980	1.12000
0.92544	1.14000
0.92065	1.16000
0.91537	1.18000
0.90956	1.20000
0.89234	1.25000
0.87054	1.30000
0.84325	1.35000
0.80964	1.40000
0.76906	1.45000
0.72118	1.50000
0.60472	1.60000
0.32900	1.80000
0.11263	2.00000
0.00210	2.40000

TABLE 23. EQUIPMENT STOCK CONSTRAINTS - FACILITY REPAIR

Provisioning Level	Price	Cube	Weight
0.	0.600000E-01	0.700000E-04	0.900000E-01
0.010038	0.385602E 05	0.108956E 02	0.742600E 02
0.020242	0.412887E 05	0.134239E 02	0.110770E 03
0.030510	0.455982E 05	0.157303E 02	0.137430E 03
0.040677	0.476761E 05	0.158575E 02	0.148500E 03
0.050985	0.488980E 05	0.161474E 02	0.161890E 03
0.061061	0.506061E 05	0.175560E 02	0.232990E 03
0.071558	0.509228E 05	0.178238E 02	0.244410E 03
0.081841	0.513963E 05	0.185254E 02	0.251260E 03
0.092377	0.520336E 05	0.192912E 02	0.266170E 03
0.102854	0.536975E 05	0.201105E 02	0.287190E 03
0.113250	0.548508E 05	0.202509E 02	0.295370E 03
0.123485	0.549306E 05	0.203761E 02	0.298010E 03
0.133796	0.555772E 05	0.204694E 02	0.302210E 03
0.143961	0.556119E 05	0.204915E 02	0.304050E 03
0.154360	0.556373E 05	0.205184E 02	0.305380E 03
0.164702	0.556508E 05	0.205348E 02	0.305940E 03
0.175078	0.557811E 05	0.210557E 02	0.310600E 03
0.185314	0.558170E 05	0.211019E 02	0.311170E 03
0.195901	0.627761E 05	0.242190E 02	0.314680E 03
0.206315	0.643504E 05	0.246067E 02	0.326350E 03
0.216339	0.643775E 05	0.246782E 02	0.329780E 03
0.226652	0.646310E 05	0.249032E 02	0.339110E 03
0.237243	0.648538E 05	0.250138E 02	0.344970E 03
0.247858	0.648685E 05	0.250789E 02	0.346570E 03
0.258077	0.648834E 05	0.251243E 02	0.348000E 03
0.268700	0.648942E 05	0.251636E 02	0.349040E 03
0.278860	0.649552E 05	0.252130E 02	0.352210E 03
0.288978	0.654058E 05	0.252905E 02	0.359780E 03
0.299512	0.654439E 05	0.252953E 02	0.361050E 03
0.309825	0.654454E 05	0.252986E 02	0.362190E 03
0.320197	0.661325E 05	0.253271E 02	0.363130E 03
0.330264	0.666878E 05	0.253495E 02	0.363970E 03
0.340802	0.668744E 05	0.254976E 02	0.373920E 03
0.350840	0.669653E 05	0.255963E 02	0.378300E 03
0.361592	0.669944E 05	0.256087E 02	0.378840E 03
0.371794	0.669971E 05	0.256190E 02	0.379300E 03
0.382284	0.670046E 05	0.256334E 02	0.379870E 03
0.393071	0.670192E 05	0.256479E 02	0.380560E 03
0.403225	0.670414E 05	0.256969E 02	0.381670E 03
0.413533	0.671548E 05	0.257336E 02	0.383310E 03
0.423845	0.673995E 05	0.258058E 02	0.386620E 03
0.434220	0.677230E 05	0.258190E 02	0.386930E 03
0.444796	0.677475E 05	0.258258E 02	0.387240E 03
0.455629	0.677780E 05	0.258290E 02	0.387450E 03
0.465706	0.677798E 05	0.258290E 02	0.387450E 03
0.476006	0.677897E 05	0.258290E 02	0.387450E 03
0.486534	0.677980E 05	0.258290E 02	0.387450E 03

TABLE 23. EQUIPMENT STOCK CONSTRAINTS - FACILITY REPAIR (Continued)

Provisioning Level	Price	Cube	Weight
0.497295	0.678015E 05	0.258328E 02	0.387570E 03
0.507631	0.688395E 05	0.258339E 02	0.387690E 03
0.517817	0.694340E 05	0.258481E 02	0.388460E 03
0.527981	0.694372E 05	0.258495E 02	0.389390E 03
0.538010	0.694382E 05	0.258518E 02	0.390470E 03
0.548229	0.694391E 05	0.258566E 02	0.391670E 03
0.558592	0.697803E 05	0.258586E 02	0.392630E 03
0.569304	0.700332E 05	0.258977E 02	0.395920E 03
0.579751	0.701759E 05	0.259099E 02	0.396290E 03
0.590312	0.702300E 05	0.259380E 02	0.398820E 03
0.600870	0.702450E 05	0.259753E 02	0.399520E 03
0.611049	0.706917E 05	0.260125E 02	0.400580E 03
0.621155	0.707150E 05	0.260404E 02	0.403990E 03
0.631259	0.709164E 05	0.262394E 02	0.409280E 03
0.642048	0.710768E 05	0.262874E 02	0.411050E 03
0.652686	0.713482E 05	0.263599E 02	0.414430E 03
0.662980	0.713817E 05	0.265386E 02	0.424780E 03
0.673057	0.722268E 05	0.265677E 02	0.425590E 03
0.683069	0.723509E 05	0.268287E 02	0.430530E 03
0.693152	0.724978E 05	0.269688E 02	0.433890E 03
0.703307	0.725596E 05	0.272979E 02	0.435319E 03
0.713538	0.726013E 05	0.273108E 02	0.435979E 03
0.723754	0.726015E 05	0.273108E 02	0.435979E 03
0.733958	0.727723E 05	0.273164E 02	0.436289E 03
0.744455	0.736752E 05	0.276124E 02	0.443699E 03
0.755040	0.736766E 05	0.276159E 02	0.445379E 03
0.765055	0.736779E 05	0.276194E 02	0.447059E 03
0.775204	0.736841E 05	0.276375E 02	0.448499E 03
0.785413	0.748129E 05	0.276491E 02	0.450199E 03
0.795456	0.748577E 05	0.287904E 02	0.462199E 03
0.805990	0.748964E 05	0.288490E 02	0.463569E 03
0.816504	0.781256E 05	0.306639E 02	0.475369E 03
0.826998	0.781645E 05	0.307648E 02	0.480489E 03
0.837391	0.782297E 05	0.309402E 02	0.484709E 03
0.847657	0.791727E 05	0.310499E 02	0.486819E 03
0.857723	0.798509E 05	0.313324E 02	0.497669E 03
0.868020	0.815153E 05	0.314875E 02	0.507529E 03
0.878058	0.818420E 05	0.315920E 02	0.510269E 03
0.888190	0.821719E 05	0.316618E 02	0.515489E 03
0.898229	0.889137E 05	0.349365E 02	0.520659E 03
0.949092	0.899572E 05	0.355478E 02	0.527139E 03

TABLE 24. SUPPORT SHIP STOCK CONSTRAINTS - FACILITY REPAIR

Provisioning Level	Price	Cube	Weight
0.013599	0.629000E 04	0.107870E 01	0.137500E 02
0.026430	0.129650E 05	0.123940E 01	0.215000E 02
0.040424	0.155750E 05	0.623940E 01	0.472000E 02
0.051073	0.168100E 05	0.638940E 01	0.506000E 02
0.061194	0.170960E 05	0.647270E 01	0.546000E 02
0.073162	0.174890E 05	0.653470E 01	0.591900E 02
0.087324	0.188330E 05	0.954980E 01	0.611900E 02
0.103877	0.191380E 05	0.100908E 02	0.679900E 02
0.123567	0.196960E 05	0.103623E 02	0.713500E 02
0.134770	0.199020E 05	0.105123E 02	0.715400E 02
0.146989	0.202110E 05	0.106103E 02	0.805400E 02
0.158578	0.203730E 05	0.106745E 02	0.806700E 02
0.179626	0.249780E 05	0.108020E 02	0.851400E 02
0.191900	0.251330E 05	0.109320E 02	0.871400E 02
0.205012	0.252880E 05	0.110130E 02	0.872400E 02
0.219020	0.254430E 05	0.110433E 02	0.907400E 02
0.232252	0.261430E 05	0.110433E 02	0.907400E 02
0.247205	0.263930E 05	0.113433E 02	0.949000E 02
0.263122	0.266430E 05	0.116433E 02	0.990600E 02
0.279856	0.267540E 05	0.116542E 02	0.993700E 02
0.295452	0.278940E 05	0.126542E 02	0.109370E 03
0.309603	0.285940E 05	0.126542E 02	0.109370E 03
0.322947	0.288440E 05	0.126990E 02	0.111870E 03
0.336865	0.289880E 05	0.126990E 02	0.111870E 03
0.347754	0.291070E 05	0.126990E 02	0.111870E 03
0.358721	0.292878E 05	0.126990E 02	0.111870E 03
0.369619	0.301878E 05	0.126990E 02	0.111870E 03
0.380498	0.306578E 05	0.127109E 02	0.112100E 03
0.400760	0.334578E 05	0.127109E 02	0.112100E 03
0.411292	0.348578E 05	0.127109E 02	0.112100E 03
0.421776	0.353178E 05	0.127228E 02	0.112330E 03
0.436602	0.355243E 05	0.127347E 02	0.112640E 03
0.448928	0.400873E 05	0.138798E 02	0.146390E 03
0.459890	0.416598E 05	0.140057E 02	0.151640E 03
0.473923	0.442698E 05	0.190057E 02	0.177340E 03
0.484488	0.470948E 05	0.200057E 02	0.187340E 03
0.496256	0.484548E 05	0.202620E 02	0.195830E 03
0.507830	0.506813E 05	0.238766E 02	0.211130E 03
0.519282	0.515161E 05	0.246778E 02	0.227540E 03
0.530851	0.515257E 05	0.246778E 02	0.227540E 03
0.542678	0.515269E 05	0.246778E 02	0.227540E 03
0.552734	0.515279E 05	0.246843E 02	0.227660E 03
0.563085	0.530054E 05	0.246880E 02	0.227850E 03
0.574462	0.532518E 05	0.252167E 02	0.228460E 03
0.585417	0.532570E 05	0.252167E 02	0.228460E 03
0.596582	0.532615E 05	0.252167E 02	0.228460E 03

TABLE 24. SUPPORT SHIP STOCK CONSTRAINTS - FACILITY REPAIR (Continued)

Provisioning Level	Price	Cube	Weight
0.607959	0.532615E 05	0.252167E 02	0.228460E 03
0.619212	0.592602E 05	0.253625E 02	0.232640E 03
0.629817	0.591205E 05	0.255606E 02	0.234870E 03
0.640934	0.604857E 05	0.255758E 02	0.235620E 03
0.651107	0.605318E 05	0.256687E 02	0.236540E 03
0.662297	0.609709E 05	0.256760E 02	0.237270E 03
0.673340	0.610476E 05	0.257192E 02	0.238270E 03
0.684567	0.610617E 05	0.257237E 02	0.238410E 03
0.695094	0.615316E 05	0.259836E 02	0.241410E 03
0.705915	0.627666E 05	0.266301E 02	0.253510E 03
0.717123	0.628300E 05	0.267538E 02	0.256850E 03
0.728508	0.628513E 05	0.268116E 02	0.258020E 03
0.738619	0.628948E 05	0.268615E 02	0.261020E 03
0.749395	0.630470E 05	0.269135E 02	0.262720E 03
0.760290	0.63579[illegible]E 05	0.269577E 02	0.264570E 03
0.771011	0.661763E 05	0.269597E 02	0.264840E 03
0.781759	0.668315E 05	0.277490E 02	0.270660E 03
0.792135	0.674929E 05	0.281324E 02	0.284920E 03
0.802574	0.675528E 05	0.281826E 02	0.287540E 03
0.812794	0.677093E 05	0.281980E 02	0.285720E 03
0.822969	0.682411E 05	0.283949E 02	0.293540E 03
0.833223	0.693328E 05	0.287009E 02	0.307770E 03
0.843854	0.712416E 05	0.290421E 02	0.320180E 03
0.853879	0.735351E 05	0.300962E 02	0.332230E 03
0.864095	0.749231E 05	0.306444E 02	0.334550E 03
0.874334	0.814002E 05	0.358112E 02	0.367430E 03
0.884668	0.849360E 05	0.358410E 02	0.369020E 03
0.894776	0.926071E 05	0.362395E 02	0.392260E 03
0.905034	0.958785E 05	0.373499E 02	0.398550E 03
0.915291	0.102560E 06	0.387780E 02	0.471000E 03
0.925406	0.105405E 06	0.409594E 02	0.496810E 03
0.935480	0.108345E 06	0.420163E 02	0.519590E 03
0.945650	0.119224E 06	0.462787E 02	0.553760E 03

The recommended depot stock list is shown in Table A-15. The depot stock list was determined for a depot supplying 42 equipments at the 99% provisioning level for a six month stock period. Table A-15 has the same format as described previously for Table A-13 with three exceptions. Two of the exceptions involve the additional fourth and fifth entries as follows:

Entry	Remarks
Usage/3 Months	This entry shows the number of the part type expected (on the average) to be issued every three months from the depot for the 42 equipments.
Spares	This entry shows the number of the part type over and above the usage per 3 months which was required in order to reach the 99% provisioning level specified for the depot.

The total of usage per 3 months and spares is the number of the part type allowed as stock by the depot. This total is shown in entry #3 under allowed quantity. The third exception is the rate entry which for the depot is the rate for 42 items for a six month stock period.

The depot stock list recommends stocking a total of 14,563 items (depth) which represents a range of 2,070 part types. The total cost of this stocking including 3 month usage plus insurance back up is computed to be $491,260.84 which has a weight of 2,995 pounds and a volume of 225 cubic feet.

Table 25 shows the constraints of cost, weight, and cube versus provisioning level. Table 25 is based on the insurance back up items only. Figure 18 presents the constraints in graphical format.

EMEC AND ESO APL STOCK ITEMS

Calculations were performed using the computer program to determine the provisioning level of the 4 June 1965 Allowance Parts List compiled by the Electronics Supply Office. The allowed quantities were taken from the Allowance Parts List. The AN/SPS-40 equipment parts list was received from the Electronics Supply Office in the form of a deck of IBM cards.

The Allowance Parts List's allowed quantities contained 1,224 different parts types (range) and a total of 2,032 parts being allowed (depth). Of the 1,224 different parts types, 1,013 were represented by Federal Stock Numbers and 211 were represented by manufacturer's numbers.

Calculations were also performed using the computer program to determine the provisioning level of the Electronics Maintenance Engineering Center Allowance Parts List. The EMEC Allowance Parts List contained 987 different part types (range) and a total 1,548 parts being allowed (depth). Of the 987 different part types, 951 were represented by Federal Stock Numbers and 36 were represented by manufacturer's numbers.

Investigations of the provisioning levels calculated for the EMEC and ESO APL's were conducted. It was determined that Vitro and EMEC had established different lists of parts which were to be considered for stocking aboard ship. An example of the type of problem which occurred can be illustrated by three items shown below:

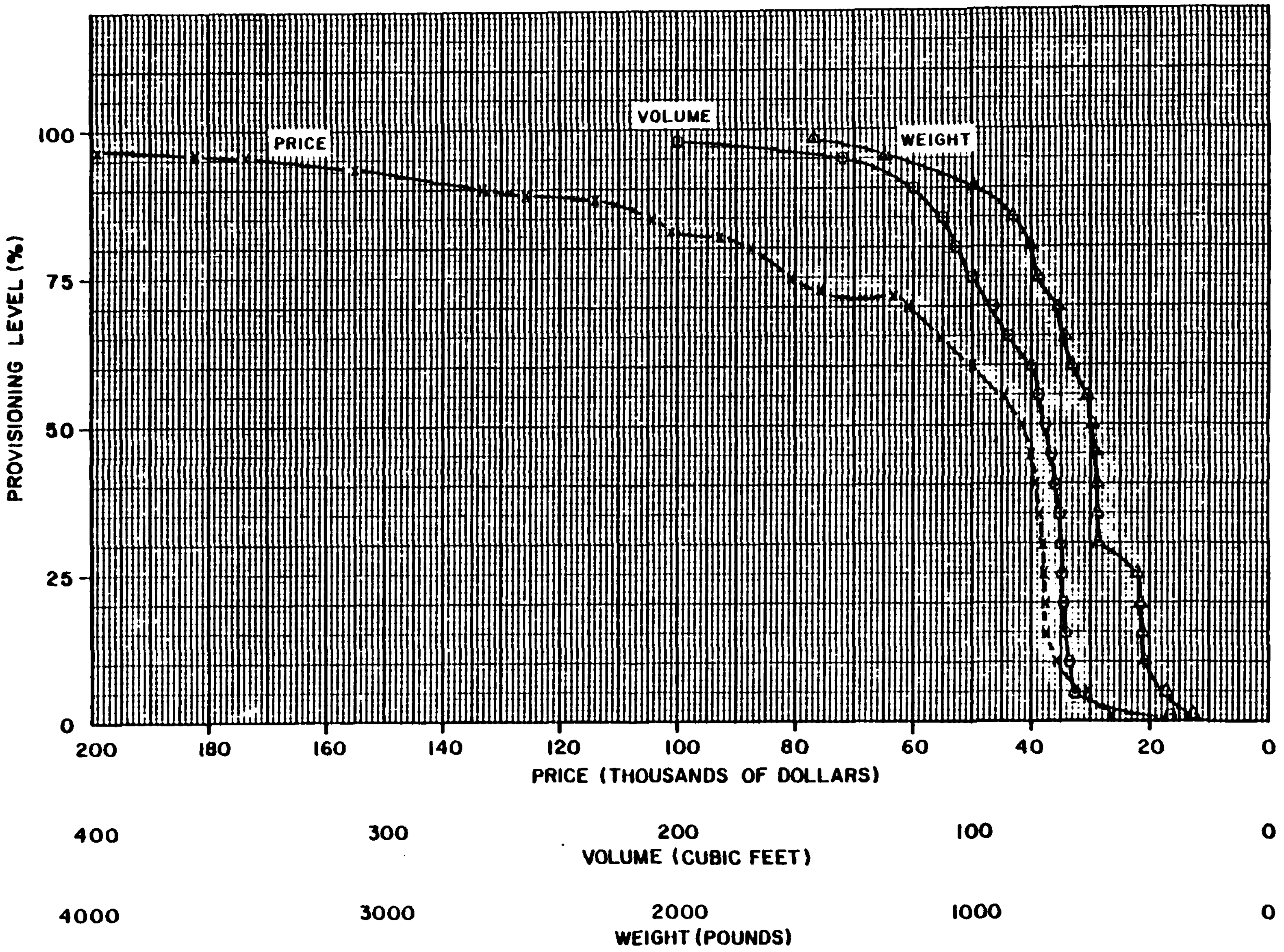


Figure 18. Depot Stock Constraints Graph - Facility Repair

TABLE 25. DEPOT STOCK CONSTRAINTS - FACILITY REPAIR

Provisioning Level	Price	Cube	Weight
0.010078	0.259715E 05	0.256909E 02	0.321730E 03
0.020231	0.263761E 05	0.257878E 02	0.328110E 03
0.030461	0.266083E 05	0.259092E 02	0.337740E 03
0.040569	0.307293E 05	0.347323E 02	0.649419E 03
0.050806	0.309166E 05	0.350567E 02	0.657499E 03
0.060985	0.310096E 05	0.350892E 02	0.659709E 03
0.071141	0.311181E 05	0.352022E 02	0.663269E 03
0.081590	0.314634E 05	0.352801E 02	0.666619E 03
0.091832	0.318803E 05	0.354013E 02	0.671129E 03
0.101843	0.359592E 05	0.428363E 02	0.675219E 03
0.112448	0.371595E 05	0.428401E 02	0.675479E 03
0.122558	0.373604E 05	0.428891E 02	0.677488E 03
0.132935	0.375246E 05	0.429763E 02	0.681099E 03
0.143166	0.376015E 05	0.429874E 02	0.682399E 03
0.153621	0.376366E 05	0.429912E 02	0.682809E 03
0.163846	0.376561E 05	0.430025E 02	0.686289E 03
0.174430	0.376625E 05	0.430088E 02	0.686529E 03
0.184967	0.378524E 05	0.430289E 02	0.687779E 03
0.195300	0.379019E 05	0.430396E 02	0.688719E 03
0.205809	0.379525E 05	0.430736E 02	0.690009E 03
0.216051	0.380060E 05	0.431061E 02	0.692009E 03
0.226531	0.380671E 05	0.431258E 02	0.692818E 03
0.236782	0.381480E 05	0.431634E 02	0.694609E 03
0.246836	0.381615E 05	0.431804E 02	0.695229E 03
0.257024	0.381634E 05	0.431845E 02	0.696818E 03
0.267655	0.381665E 05	0.431886E 02	0.698258E 03
0.277921	0.381886E 05	0.431907E 02	0.699338E 03
0.288548	0.382106E 05	0.432014E 02	0.700548E 03
0.298928	0.383279E 05	0.582125E 02	0.704308E 03
0.309213	0.383556E 05	0.582359E 02	0.705798E 03
0.319241	0.384657E 05	0.582477E 02	0.706758E 03
0.329469	0.384745E 05	0.582588E 02	0.707598E 03
0.339698	0.385478E 05	0.583066E 02	0.708788E 03
0.349924	0.387406E 05	0.583545E 02	0.711338E 03
0.360363	0.388020E 05	0.583651E 02	0.712128E 03
0.370946	0.390523E 05	0.584143E 02	0.714208E 03
0.381054	0.391242E 05	0.584170E 02	0.715788E 03
0.391189	0.391548E 05	0.584380E 02	0.717578E 03
0.401838	0.392951E 05	0.584755E 02	0.719516E 03
0.412122	0.393635E 05	0.584953E 02	0.721278E 03
0.422311	0.395155E 05	0.585537E 02	0.726948E 03
0.432668	0.398209E 05	0.588864E 02	0.733588E 03
0.442731	0.398620E 05	0.588984E 02	0.734548E 03
0.453073	0.399981E 05	0.589224E 02	0.736316E 03
0.463194	0.400573E 05	0.589546E 02	0.738598E 03
0.473575	0.401998E 05	0.590512E 02	0.742306E 03
0.483738	0.410125E 05	0.592055E 02	0.752708E 03
0.494119	0.415585E 05	0.592425E 02	0.754628E 03
0.504160	0.417602E 05	0.592668E 02	0.755768E 03
0.514216	0.432731E 05	0.604740E 02	0.764068E 03

TABLE 25. DEPOT STOCK CONSTRAINTS - FACILITY REPAIR (Continued)

Provisioning Level	Price	Cube	Weight
0.524314	0.432707E 05	0.605006E 02	0.765778E 03
0.534578	0.436451E 05	0.606050E 02	0.771478E 03
0.544662	0.450895E 05	0.606634E 02	0.773028E 03
0.554818	0.451099E 05	0.606887E 02	0.774188E 03
0.565260	0.451460E 05	0.607237E 02	0.776678E 03
0.575387	0.452054E 05	0.607983E 02	0.780738E 03
0.585571	0.492645E 05	0.644263E 02	0.788978E 03
0.595748	0.504486E 05	0.659323E 02	0.804358E 03
0.605864	0.508116E 05	0.660900E 02	0.814438E 03
0.615960	0.527650E 05	0.661245E 02	0.815798E 03
0.626051	0.531094E 05	0.672790E 02	0.850728E 03
0.636295	0.537916E 05	0.673492E 02	0.853778E 03
0.646459	0.547942E 05	0.682964E 02	0.882798E 03
0.656743	0.561010E 05	0.694079E 02	0.887968E 03
0.666852	0.569924E 05	0.695296E 02	0.894578E 03
0.677012	0.580363E 05	0.696002E 02	0.898078E 03
0.687094	0.589850E 05	0.700301E 02	0.914858E 03
0.697347	0.615456E 05	0.708173E 02	0.920258E 03
0.707499	0.624472E 05	0.709659E 02	0.924358E 03
0.717593	0.626003E 05	0.710772E 02	0.927708E 03
0.727877	0.757671E 05	0.764509E 02	0.960308E 03
0.738012	0.778020E 05	0.765274E 02	0.965728E 03
0.748089	0.803852E 05	0.783613E 02	0.100208E 04
0.758131	0.852976E 05	0.793750E 02	0.102402E 04
0.768265	0.859833E 05	0.794576E 02	0.103102E 04
0.778424	0.861390E 05	0.795623E 02	0.103304E 04
0.788601	0.861514E 05	0.796239E 02	0.103462E 04
0.798731	0.877943E 05	0.800111E 02	0.105164E 04
0.808893	0.899063E 05	0.818894E 02	0.106985E 04
0.818966	0.925146E 05	0.821137E 02	0.108205E 04
0.829127	0.102498E 06	0.857004E 02	0.110178E 04
0.839301	0.104093E 06	0.857596E 02	0.110419E 04
0.849432	0.105094E 06	0.859236E 02	0.111064E 04
0.859556	0.108559E 06	0.877845E 02	0.112547E 04
0.869714	0.108637E 06	0.878032E 02	0.112624E 04
0.879816	0.114097E 06	0.878784E 02	0.113099E 04
0.889821	0.126010E 06	0.948457E 02	0.117691E 04
0.899883	0.133674E 06	0.990978E 02	0.119190E 04
0.909971	0.137319E 06	0.992741E 02	0.119980E 04
0.920006	0.141253E 06	0.999203E 02	0.123454E 04
0.930020	0.155682E 06	0.107801E 03	0.131730E 04
0.940063	0.162671E 06	0.109078E 03	0.134856E 04
0.950109	0.173917E 06	0.130562E 03	0.145916E 04
0.960117	0.183120E 06	0.133493E 03	0.152171E 04
0.970128	0.205641E 06	0.149877E 03	0.191367E 04
0.980133	0.217064E 06	0.153492E 03	0.200939E 04
REPLENISHMENT TOTAL FOR	PRICE----WEIGHT----CUBE		
	226,104.19	773.209	78.048

1. 3CR-7, 1N5960-983-5990, diode, source code is P1, maintenance code is 4Z.
2. 5A8W-12, 9Z6145-655-2728, cable assembly, source code is P1, maintenance code is 4Z4.
3. 4U-1, 9C4720-873-2682, nose assembly, source code is P1, maintenance code is 4Z.

Vitro considered that items 1 and 3 should be considered for stocking aboard ship but EMEC considered that only item 1 should be considered for stocking aboard ship. Analysis of the Vitro and EMEC stock lists produced approximately 200 to 300 part types which Vitro had considered as stockable aboard ship and EMEC had considered as NOT stockable aboard ship. It was found that the basis for EMEC's difference of opinion was that the ship could fabricate the 200 to 300 part types in question and therefore should not carry these items per se.

The above discrepancy was not discovered until late in the program after the stock lists had been computed. The ESO APL had a provisioning level of 1% and the EMEC APL had a provisioning level of 8%, but the above discussion shows that the proper base had not been used in the evaluation. This problem occurred because it is not possible to determine from the maintenance codes those items which are shipboard installable and are also to be fabricated by the ship.

A study was made to determine the best way to adjust the EMEC APL provisioning level to reflect its true value. The method chosen was to find those items which would have the greatest effect in degrading the provisioning level rather than adjust for the 200 to 300 items with the improper coding.

The following list of 15 items were found, which according to the probability calculations, require greater depth than shown in the EMEC APL.

FSN	NAME	PROBABILITY AT EMEC STOCK LEVEL	CUMULATIVE PROTECTION
5960-583-4396	6952	.9595	.9595
5960-170-4573	2BP1	.9862	.9462
5960-892-0975	GV5A-140	.9894	.9361
5960-188-0820	2C53	.9974	.9336
5960-296-0517	5ADP1	.9862	.9207
5960-272-9199	CK6213	.9971	.9180
5840-769-1103	FAULT DETECTION UNIT	.9774	.8972
5840-439-6340	FILTER MODULATOR	.9900	.8882
5840-798-5600	FILTER OUTPUT SWITCH	.9875	.8771
5840-798-4950	RECEIVER GATING & TRIGGER DISTRIBUTION	.9871	.8656
5840-764-5294	VIDEO GATING & DISTRIBUTION GENERATOR	.9847	.8523
5840-798-4952	15MC-24MC CONVERTER	.9841	.8387
5915-715-2350	REJECTION FILTER	.9824	.8239
5960-067-9364	E38	.9769	.8048
5960-819-2275	7651	.9960	.8015

These 15 items show that the EMEC stock list cannot exceed a provisioning level of 80%. Since the other parts within the radar are not protected to 100%, there will be further degradation of the 80%. The exact value of the EMEC stock list cannot be determined by hand calculation, but it is estimated to be in the range of 65-75%. Since the EMEC stock list is 65-75% rather than 8%, the following points are brought to light.

[illegible] There must be an adequate means of specifying the maintenance characteristics of each part.

[illegible] The program is very sensitive to maintenance policy.

[illegible] Different stock lists which are to be compared must have the proper base (namely the parts being considered and their associated maintenance and essentiality code.

Since the above problem was found to exist in the EMEC-Vitro comparison, the [illegible] provisioning level determined for ESC APL is also highly suspect. It is not possible to make an adjustment to the ESC APL provisioning level figure, however, since their maintenance policy has not been verified.

COMPARISON OF RESULTS

During Phase II three different equipment stock lists were investigated and during Phase I six different equipment stock lists were investigated. All nine of these stock lists are presented in Table [illegible] so that they may be compared.

Table [illegible] lists those parts which were allowed stock quantities by the Phase II [illegible] generated stock list, but were not allowed spares by the ESC APL. The listing of Table [illegible] shows those parts allowed spares by Vitro but were not allowed spares by the EMEC APL listing. Some of these items (200 [illegible]) are those EMEC did not consider for ship stocking. Table [illegible] contains those parts which the APL [illegible] which the Vitro stock list did [illegible] and Table [illegible] shows the parts which the EMEC APL listing [illegible] [illegible] Tables [illegible] present the differences [illegible] Phase [illegible] stock list as compared with both the ESC and EMEC APLs.

TABLE 26. EQUIPMENT STOCK LIST COMPARISON - Phase I and II

	Stock List Identification	% Calculated Provisioning Level	Range-No. Of Different Part Types	Depth-Total No. of Parts	Cost (Dollars)	Weight (Pounds)	Cube (Cu. Ft.)
PHASE I	Critical/Non-Critical Parts (All repairs by ET)	90.0	1,809	2,103	$78,058.	1,472	174
	Critical Parts Only (Repairs by ET)	90.0	1,502	1,741	$75,087.	1,400	172
	Critical Parts-Min. Depth (Repair by ET)	93.9	2,043	2,337	$79,190.	1,494	190
	Critical/Non-Critical Parts and Assemblies (Selected Repairs by Manufacturer)	94.1	1,442	1,698	$131,326.	1,331	155
	February 1963 APL	0.5	1,161	2,132	$93,867.	928	119
	November 1964 APL	1.0	1,297	2,455	$93,620.	1,006	86
PHASE II	June 1965 APL	1.0*	1,224	2,032	$69,704	487	27
	EMEC APL	8.4*	987	1,548	$67,370.	421	19
	Critical/Non-Critical Parts and Assemblies (Selected Repairs by Module Repair Facility)	94.9	1,480	2,095	$89,957.	527	36

*Incomplete evaluation - see text.

TABLE 27. PARTS PROVISIONED BY VITRO AND NOT ESC

2N30107134603	9Z53407984968	9N59052792528	9N59108395734
1N30200202775	2N53558014240	9N59052792530	9N59108501502
2N30205800107	2N58400142607	9N59052793497	9N59109892210
2N30208375811	2N58400202785	9N59052793500	1N59157152350
2N30208995193	1N58407152351	9N59052793503	1N59157984963
1N30405809749	2N58407159451	9N59052992010	9N59300229964
9Z31100338453	2N58407159531	9N59052992013	9N59302302561
9Z31100338454	2N58407321925	9N59052992040	9N59306832814
1931101556190	2N58407693593	9N59052992059	9N59307159426
1931101568039	2N58407984945	9N59055185593	9N59307159580
1931101588247	2N58407984961	9N59055189362	9N59307873711
9Z31101982930	1N58408478005	9N59055392032	9N59307873712
9Z31107319145	1N58409188370	9N59055394565	9N59307873713
9Z31107319146	1N58409238307	9N59055427648	9N59308013773
9Z31107319147	1N58409564946	9N59055428053	9N59352017043
1N41308378196	1N58409763269	9N59055429799	9N59352049802
9G41408930145	2N58409764889	9N59055429981	9N59355527613
1N43207335279	1N58409764891	9N59055563041	9N59355527720
1N44407134444	1N58409873453	9N59055566420	9N59355772338
9C45400202788	1N58457159422	9N59055811714	9N59355813958
9C47302747500	9N59051124355	9N59056655468	9N59356153914
9C47302782589	9N59051858490	9N59056884124	9N59356157833
9C47302892697	9N59051858510	9N59057523420	9N59356172849
9C47305558203	9N59051858516	9N59057523970	TX59356177551
9C47306400830	9N59051908874	9N59057523974	TX59357166947
9C47306405113	9N59051908883	9N59058233482	9N59357212675
9C47306405119	9N59051908885	9N59058233567	1N59357649338
2R47306407201	1N59051914936	9N59058263805	TX59357906962
2R47307200461	9N59051920619	1N59058394061	TX59357906964
9C48100202784	9N59051920626	9N59058394064	9N59358032313
1N51200186021	9N59051923973	9N59058417461	9N59358126344
1N53150589733	9N59051923981	1N59058926951	9N59358230487
9Z53157256310	9N59051924504	9N59100880385	9N59358418092
9Z53300202791	9N59051955571	9N59101261619	TX59358467980
1953300546894	9N59051956754	9N59101269170	TX59358552586
1953301542456	9N59051956761	9N59102709001	1N59358795116
1953301719916	9N59052215848	1N59104741901	1N59359913379
1953301986195	9N59052524018	9N59105569440	9G59402582462
9Z53302518839	9N59052547096	9N59105773183	9G59405005373
1953302651095	9N59052586918	9N59105830735	9G59405028469
1953302859836	9N59052679524	9N59106817046	9G59405770123
KZ53302920580	9N59052791692	1N59107324900	9G59406298127
KZ53305796859	9N59052791718	9N59108123918	1N59408732692
KZ53305840263	9N59052791721	9N59108181635	9G59408937485
1953305840266	9N59052791752	9N59108189758	1N59450803432
KZ53306181603	9N59052791890	9N59108231068	9N59457024880
9Z53308732681	9N59052791921	1N59108231969	1N59457244743
9Z53309763271	9N59052791930	9N59108265466	9N59457373195
1N53400202774	9N59052792515	9N59108339280	1N59457808005
9Z53402056552	9N59052792527	9N59108354662	9N59458127909

TABLE 27. PARTS PROVISIONED BY VITRO AND NOT ESO (Continued)

9N59459729089	2N66258208458	METAL1/4+18	11+140
1N59500202770	1N66258208459	MIL+N+994	11+146
9N59507087067	1N66258208460	MS21900+12C	11+260
9N59508993420	2N66258208461	MS21902+D4	11+261
9N59508993421	2N66258380147	MS21902+D8	11+277
1N59509763273	1N66258380148	MS21908D4	1298+3/8NPT
9N59600824139	2N66258729212	MS21909D4	1652+8
9N59602732415	2N66258732680	MS21911+8C	1724C
9N59605196954	1N66458405693	MS21913+D10	194080364
9N59605562621	1N66858729216	MS21921+D4	194081350
9N59605815603	AN23858	MS21921+D8	194081351
9N59605834071	AN6290+10	MS21921+12C	19776+1
9N59606655192	AN6290+12	MS21921+8C	1988HMS1728
9N59607250527	AN6290+4	MS21922+R8	2+113
9N59607295499	AN6290+5	MS28775+017	2+259
1N59607955570	AN6290+6	MS28775+212	2+261
9N59608120480	AN6290+8	MS3106E12S3P	2P50N+SS
9N59608336041	AN837+8C	MS3106E14S2P	2141
9N59609683858	AN924+12C	MS35671+33	2329F0045+2
1N59609835990	AN924+3C	MS9021+008	2329F0045+3
1N59609841175	AN924+8C	MS915283K28	2329F0045+4
9N59709193044	AN924+8D	NA+1947	2329F0045+5
9N59858795601	AVHC+12MS50	NE01+3/4ID	2329F0045+6
1N59959198519	AVHC+2+M	NE013/16ID	2329F0045+7
9N59990229963	AVHC+4+MS14	NS4AW0208	2329F0045+8
9N59997134349	AVHC+8+6F	PD3127	2329F0045+9
9N59997134459	AVHN+12MS14	PD347001308	2333B0005
9N59997314416	AVHN+4+MS14	RE025N380085	2333B0006
9N59998375825	AVHN+4MS15	RFL172	2333C0004
9N59998375826	AVHN+8+MS14	RFL173	2338C0114
9N59998375827	BIJURA+2835	RFL174	2338D0146
9N59998375828	BIJURB+1061	RFL175	263080291
9N59998379496	BIJURB+1371	SSRS77R8	263080378+5
1N59998600832	BIJURB+3601	ST SR+434	263080412
1N59999502885	B8+8	ST SR+500L	263081687
9G62102647010	C+2478	TEF3/4DIA	2630D0007
1N62105041617	CH05A3NC205K	TYPE 304	2630D0433
9G62202840289	C3+3	X1980+XA	2763HMS26
9G62401557857	D4+125	X2045X3	29904
9G62401558707	ER816D0808	Y0E130	3+4Y
9G62402239100	ER816D4+4	.3125 DIA	3/4 IPS
1N66250885411	ER822D0808	908108608W	3/4X1/2FGSS
1N66254449773	ER822D4	1525	30K
1N66254449774	ER822D4+4	1 IPS 150LB	3010+8
2N66256493274	G17+70	1/2DD+SS	31408626З
1N66257159431	JV+1	1/8 IN	39902+4
1N66257332745	JV+20	101807	39905+3
2N66257332746	K82+0006	106064+337	39913
1N66257332748	LH628R2	109074+337	39914
1N66257947812	LI+6	11+137	39919

TABLE 27. PARTS PROVISIONED BY VITRO AND NOT ESO (Continued)

4CBIBRASS	4400B1784	4400C1601	4401B0179
4FBIBRASS	4400B1785	4400C1613	4401B0217
401+117+10	4400B1786	4400C1615	4401B0240
404115+0210	4400B1787	4400C1616	4401B0244
4400B0392	4400B1789	4400C1658	4401B0246
4400B0484	4400B1790	4400C1671	4401B0252
4400B0487	4400B1791	4400C1672	4401B0270
4400B0488	4400B1793	4400C1710	4401B0271
4400B0537	4400B1795	4400C1734	4401B0274
4400B0548	4400B1802	4400C1736	4401B0351
4400B0548-2	4400B1803	4400C1772	4401B0415
4400B0835	4400B1804	4400C1779	4401B0425+2
4400B0969	4400B1806	4400C1780	4401C0009
4400B1355	4400B1807	4400C1782	4401C0010
4400B1359	4400B1808	4400C178810	4401C0013
4400B1369	4400B1812	4400C178811	4401C0017
4400B1370	4400B1825	4400C1796	4401C0035
4400B1371	4400B1938	4400C1797	4401C0042
4400B1372	4400B1946	4400C1805	4401C0044
4400B1373	4400B1947	4400C1809	4401C0046
4400B1374	4400B1979	4400C1810	4401C0047+2
4400B1375	4400B2000	4400C1811	4401C0047+3
4400B1382	4400B2031	4400C1829-2	4401C0052
4400B1394	4400B2051	4400C1829-3	4401C0053
4400B1395	4400B2053	4400C1832	4401C0059
4400B1410	4400B2085	4400C2027	4401C0245
4400B1413	4400B2088	4400C2054	4401C0251
4400B1420	4400C0310	4400D0448	4401D0021
4400B1421	4400C0310+2	4400D1248	4401D0050
4400B1422	4400C0490	4400D1407	4401F0005
4400B1423	4400C1329	4400D1409	4401F0026
4400B1426	4400C1329+2	4400D1415	4401F0207
4400B1444	4400C1349	4400D1416	47SPISTON2
4400B1445	4400C1350	4400D1490	48X48(8X8)
4400B1465	4400C1351	4400D1499	48004511
4400B1609	4400C1352	4400D1757	48981/221/4
4400B1611	4400C1368	4400D1757-2	497+4D+1
4400B1619	4400C1408	4400D1781	5/16X1 3/4
4400B1648	4400C1424	4400F1406	500+9+5
4400B1656	4400C1429	4400F1419100	5000+81W
4400B1675	4400C1430	4400F1713	5133+18
4400B1676	4400C1430+2	4400F1768129	5595+1245RD
4400B1677	4400C1481	4400F1822	6+32X2.375
4400B1724	4400C1493	4400F1823	6-32X3.75
4400B1732	4400C1500	4400F189720	790220340500
4400B1733	4400C1501	4400F189721	8+8FTX
4400B1735	4400C1502	4401B0018	820-3
4400B1774	4400C1503	4401B0019	8438181+1
4400B1777	4400C1506	4401B0033	850
4400B1778	4400C1589	4401B0041	9021+010
4400B1783	4400C1600	4401B0049	909+A+2768

TABLE 28. PARTS PROVISIONED BY VITRO AND NOT EMEC

2N30107258019	9N59352017043	53305840263	9G59402582462
1N30109836007	9N59352049802	9Z53305853217	9G59405005373
1N30200202775	9N59352590337	53306181603	9G59405005378
2N30205800107	9N59352592748	9Z53307135370	9G59405028469
2N30208226295	1N59352899748	9Z53402056552	9G59405428546
2N30208995193	9N59354396492	9Z53402869469	9G59405429333
1N30405809749	9N59355188836	9Z53405981138	9G59405770123
1N31100196387	9N59355392650	2N53406857023	9G59406132627
9Z31100338454	9N59355392651	9Z53407250969	9G59406298127
1931101568039	9N59355523036	9Z53407984968	9G59407554199
1931101588247	9N59355527613	2N53408206748	9G59408121668
9Z31101982930	9N59355527720	9Z53555560145	1N59408732692
9Z31105734244	9N59355551888	1N53556169604	1N59408930951
9Z31107311718	9N59355772336	9Z53555560145	9G59408937485
9Z31107319148	9N59355772338	2N53558014240	1N59409501175
1N31207159542	9N59355813958	58400142607	1N59457244743
1N41300551145	9N59355836325	1N58400198171	9N59457373195
1N41405902317	9N59356151108	1N58400202777	9N59505771224
1N44407134444	9N59356153914	2N58400202785	1N59507895238
9C45400202788	59356177551	1N58400732235	9N59602732415
9C47208729215	9N59356365983	1N58400732236	9N59605196954
1N47209508830	9N59356439608	1N58400732237	9N59605562621
47302747500	9N59356815681	1N58400732238	9N59605815603
47302782589	9N59356820501	2N58407134051	9N59606655192
47302892697	9N59357020127	2N58407159451	9N59606820885
47305558203	9N59357021207	2N58407321925	9N59606868085
47306400830	9N59357134200	2N58407580898	9N59606868087
9C47306405113	1N59357264150	2N58407693593	9N59607250527
9C47306405119	9N59357298036	2N58407984964	1N59607955570
47306407201	1N59357649338	2N58408383385	9N59608104928
9C47306843579	9N59357715937	2N58408383386	59709193044
47307200461	9N59357759058	58409238307	1N59758991995
9C47308156976	9N59358032312	1N58409763269	1N59759667706
9C48208148448	9N59358032313	1N58409764891	2N59857616693
1N49208742512	9N59358032315	1N58409918691	1N59858933208
1N53150589733	59358054948	1N58457159422	9N59990608643
9Z53152819481	9N59358103767	9N59050613868	9N59990868567
1N53152864888	9N59358126344	9N59051908889	9N59997134349
9Z53157206460	9N59358126345	1N59051914936	9N59997134459
9Z53157256310	9N59358144127	9N59052547110	9N59997314416
9Z53157319230	9N59358381905	9N59052791718	2N59997892197
9Z53300202791	9N59358418092	9N59052791890	9N59998375825
1953300546894	59358467980	9N59058284101	9N59998375826
1N53300583952	9N59358472600	9N59101269170	9N59998375827
9Z53302518839	59358552586	9N59105830735	9N59998375828
1953302859839	9N59358567980	9N59107524676	9N59998379495
53302920580	59358795116	9N59108395734	9N59998379496
1N53303509013	9N59358928804	1N59300198175	1N59998600832
53305796859	9N59359764890	9N59307873713	1N59999502885
1N53305802278	9G59402581931	9N59352012721	1N61207897977

TABLE 26. PARTS PROVISIONED BY [illegible] AND NOT EMEC (Continued)

1N66250885411	G17+70	X1980+XA	2630B0291
1N66254449773	JV+1	X2045X3	2630B0378+5
1N66254449774	JV+20	YOE130	2630B0412
2N66256493274	K82+0006	.3125D1A	2630B1669
1N66257159431	L1+6	908108608W	2630B1687
2N66257286029	METAL1/4+18	1525	2630D0007
2N66257286030	MIL+N+994	1+1PS150LB	2630D0433
1N66257332748	MS21900+12C	1/2DD+SS	2763HMS26
1N66257947812	MS21902+D4	1/8+1N	29904
1N66258208460	MS21902+D8	106064+337	3+4Y
2N66258208461	MS21908D4	109074+337	3/4+1PS
2N66258729212	MS21909D4	11+137	3/4X1/2FGSS
1N66458405693	MS21911+8C	11+140	30K
1N66850202743	MS21913+D10	11+146	3010+B
1N66857354689	MS21913+D6	11+260	314086263
1N66858729216	MS21921+D4	11+261	39902+4
AN23858	MS21921+D8	11+277	39904+4
AN6290+10	MS21921+12C	12+8FTX	39904+5
AN6290+4	MS21921+8C	129B+3/8NPT	39905+2
AN6290+5	MS21922+R8	1652+B	39905+3
AN6290+8	MS21922+4R	1724C	39913
AN837+8C	MS21923+12C	1940B0364	39914
AN924+12C	MS21923+8C	1940B1350	39919
AN924+3C	MS28775+017	1940B1351	4CB1BRASS
AN924+4D	MS28775+212	1940B1509	4FB1BRASS
AN924+8C	MS3106E12S3P	19776+1	401+117+10
AN924+8D	MS3106E14S2P	1988HMS1728	404115+0210
AVHC+12MS50	MS35671+33	2P50N+SS	4400B0314
AVHC+2+M	MS9021+008	2329F0024	4400B0392
AVHC+4+MS14	MS915283K2B	2329F0045+2	4400B0484
AVHC+8+6F	NA+1947	2329F0045+3	4400B0487
AVHN+12MS14	NE01+3/4+1D	2329F0045+4	4400B0488
AVHN+4+MS14	NE01+3/16+1D	2329F0045+5	4400B0537
AVHN+4MS15	NS4AW0208	2329F0045+6	4400B0548
AVHN+8+MS14	NW66520+10B	2329F0045+7	4400B0548+2
B1JURA+2835	PD3127	2329F0045+8	4400B0835
B1JURB+1061	PD347001308	2329F0045+9	4400B0969
B1JURB+1371	RE025N380085	2329F004510	4400B1355
B1JURB+3601	RFL172	2329F004511	4400B1359
B19415+1	RFL173	2329F004512	4400B1369
B8+8	RFL174	2333B0005	4400B1370
C+2478	RFL175	2333B0006	4400B1371
C147+6	SSRS77RB	2333C0004	4400B1372
C3+3	ST+SR+434	2338D0146	4400B1373
D4+125	ST+SR+500L	2344B0067	4400B1374
ER816D0808	TEF3/4D1A	2344B0067	4400B1375
ER816D4+4	TYPE304	2344C0159	4400B1382
ER822D0808	X1581	2344C0159+2	4400B1394
ER822D4	X1942+X	2344F0090	4400B1395
ER822D4+4	X1942X3	2344F0163	4400B1410

TABLE 28. PARTS PROVISIONED BY VITRO AND NOT EMEC (Continued)

4400B1413	4400B2088	4400C1796	4401C0017
4400B1420	4400C0310	4400C1797	4401C0035
4400B1421	4400C0310+2	4400C1805	4401C0042
4400B1422	4400C0434	4400C1809	4401C0044
4400B1423	4400C0490	4400C1810	4401C0046
4400B1426	4400C0646	4400C1811	4401C0047+2
4400B1444	4400C0647	4400C1829+2	4401C0047+3
4400B1445	4400C0650	4400C1829+3	4401C0052
4400B1465	4400C0712	4400C1832	4401C0053
4400B1609	4400C1329	4400C2017	4401C0059
4400B1611	4400C1329+2	4400C2027	4401C0245
4400B1619	4400C1349	4400C2054	4401C0251
4400B1648	4400C1350	4400C0448	4401D0021
4400B1656	4400C1351	4400D1214	4401D0050
4400B1675	4400C1352	4400D1407	4401F0005
4400B1676	4400C1367	4400D1409	4401F0026
4400B1677	4400C1368	4400D1415	4401F0207
4400B1709	4400C1384	4400D1416	47SPISTON2
4400B1724	4400C1384+2	4400D1490	48X48(8X8)
4400B1732	4400C1384+3	4400D1499	48004511
4400B1733	4400C1384+4	4400D1757+2	48981/221/4
4400B1735	4400C1408	4400D1781	497+4D+1
4400B1774	4400C1429	4400F1213	5/16X1 3/4
4400B1777	4400C1430	4401B0246	500+9+5
4400B1778	4400C1430+2	4400F1406	5000+81W
4400B1783	4400C1481	4400F1419100	5133+18
4400B1784	4400C1493	4400F1768129	5595+1245RD
4400B1786	4400C1500	4400F1822	6+32X2.375
4400B1787	4400C1501	4400F1823	6+32X3.75
4400B1789	4400C1502	4400F189720	790220340500
4400B1790	4400C1503	4400F189721	8T8FTX
4400B1791	4400C1506	4401B0018	820+3
4400B1793	4400C1600	4401B0019	8438181+1
4400B1795	4400C1601	4401B0033	850
4400B1802	4400C1613	4401B0041	9021T010
4400B1803	4400C1615	4401B0049	909+A+2768
4400B1804	4400C1616	4401B0179	
4400B1806	4400C1645	4401B0217	
4400B1807	4400C1658	4401B0240	
4400B1808	4400C1671	4401B0244	
4400B1812	4400C1672	4401B0252	
4400B1825	4400C1710	4401B0270	
4400B1938	4400C1734	4401B0271	
4400B1946	4400C1736	4401B0274	
4400B1947	4400C1772	4401B0351	
4400B1979	4400C1779	4401B0415	
4400B2000	4400C1780	4401B0425+2	
4400B2031	4400C1782	4401C0009	
4400B2051	4400C178810	4401C0010	
4400B2085	4400C178811	4401C0013	

TABLE 29. PARTS PROVISIONED BY ESO AND NOT VITRO

2N30100202766	9Z53158123035	2N59157135366	1N59607783817
2N30200607926	9Z53158409853	1N59158120126	9N59608249948
2N30200607927	1953302859839	2N59158381891	59608920796
2N30200607928	9Z53405851660	1N59158600861	9N59608920804
2N30205802204	9Z53405859835	9N59208344705	1N59858600841
2N30206207195	9Z53405961228	1N59308732690	9N59997135384
2N30207314417	9Z53406770402	9N59308783159	9N59997311878
2N30207314418	1N53407541899	1N59350205791	9N59998379494
2N30207314419	1953408120474	9N59352323758	2N61058993424
2N30207314420	9Z53550498572	9N59355816400	1N61450808733
2N30207314425	1953558132078	9N59356859396	1N61457522415
2N30207314426	1N58400202760	2N59357311876	1N61457548159
2N30207314427	2N58400732231	2N59357311885	2N66257984960
2N30207314428	2N58407135382	9N59357335274	2N66258600862
2N30207314429	1N58407695425	9N59358795113	1N66450202787
2N30207314431	1N58407701914	9N59358839302	AN3436+5+3
2N30207324902	1N58407701915	1N59359563036	AN3436+5+5
2N30207324903	1N58407726642	1N59359913374	BR9CXG7V3V5
2N30207324906	1N58407726643	9G59405005378	B19460+1
2N30207328530	1N58407726644	9G59405005381	D19391+1
2N30207691087	1N58407727907	9G59405005388	EXCELON7X6
2N30208014229	2N58407873709	9G59405428547	FX5E103
2N30208014230	1N58407873725	1N59407873726	MS171495
2N30208014231	2N58407984948	9N59457152353	1525
2N30208014232	2N58408119893	9N59458600805	10+052
2N30208209262	2N58408600855	9N59500202782	10+182
2N30208209263	1N58408943033	1N59500581130	104895/8DIA
2N30208226295	9N59051711998	9N59505428549	16TB4
2N30208398972	9N59052792616	9N59506207212	2329B0019+2
2N30208398973	9N59052793506	9N59507314422	2329D0083
2N30208398974	9N59052793837	9N59507328524	2329F0094
2N30208398975	9N59052992020	9N59507985668	2333C0012
2N30208398976	9N59052992046	9N59508180207	2333C0013
2N30208794036	59055495348	9N59508180209	2338F0220
2N30209850201	9N59055770435	9N59508183999	2344B0066
2N30407691079	9N59055771827	9N59508381908	2344C0042
2N30407691080	59055777411	9N59508381909	2344C0166
2N30407691082	9N59055814990	9N59508381911	2344C0166+2
9Z31104403885	59058034582	9N59508381912	2344D0144
9Z31105405199	9N59058123178	9N59508381913	2344F0124
1N31109782858	9N59058422968	9N59508381930	2344F0164
2N44408378047	9N59058989305	9N59508381938	2344F0165
9C47308729213	9N59100160591	9N59508381940	2630B0349
1N48204449775	9N59107895241	9N59508384369	2630B0354
1N48204449776	9N59108130906	1N59508600808	36675+14
2N53106134287	9N59108169909	9N59508729218	39916
9Z53106557511	9N59108225683	9N59509647450	4400B0152
9Z53152980950	9N59108908933	9N59606178864	4400B0198
1953155987284	9N59108927654	9N59606868388	4400B0340
9Z53156875126	1N59157135365	1N59607243466	4400B0436

TABLE 29. PARTS PROVISIONED BY ESO AND NOT VITRO (Continued)

4400B0493
4400B0549
4400B0714
4400B0715
4400B0716
4400B0717
4400B0722
4400B1463
4400B1463+2
4400B1477
4400B2086
4400C0193
4400C1265
4400C1265+2
4400C1266
4400C1267
4400C1267+2
4400C1268
4400C1279
4400C1864
4400C1864+2
4400C1864+3
4400C1864+4
4400C1866
4400C1866+2
4400C1866+3
4400C1866+4
4400C1866+5
4400C1866+6
4400D0904+4
4400D0904+5
4400D1001
4400D1134
4400D1716
4400F0524
4400F0525
4400F0526
4400F0916
4400F1289
4400F1291
4400F1293
4400F1295
4400F1299
4400F1800

TABLE 30. PARTS PROVISIONED BY EMEC AND NOT VITRO

9C47305552590	59158381891	4400B2086
9Z53301943713	59158600861	4400C1178
1953301979601	1N59159501149	4400C1240
1953301986176	9N59350202758	4400F1883
1953302351675	59350205791	4400F1884
1953302917340	9N59352229913	4400F1884+2
1953306418241	9N59352408166	4401C0036
9Z53308564004	9N59355390436	
9Z53309763267	9N59355680849	
58400202760	59357311876	
2N58407159529	59357311885	
2N58407159541	59357335274	
2N58407335283	9N59358600822	
58407873709	59359913374	
58407984948	9G59409836099	
2N58409667707	59457152353	
1N58409667708	9N59457335275	
9N59051022740	59458600805	
9N59051920660	59500202782	
9N59052494225	59505428549	
9N59052793505	59506207212	
9N59052793514	59507314422	
9N59052793519	59507328524	
9N59052991971	59508381908	
59052992020	59508381909	
59052992044	59508381911	
9N59052992044	59508381930	
9N59055525490	59508384369	
9N59057135296	9N59500785860	
9N59058034582	9N59508600818	
59058989305	9N59508600819	
9N59100612957	9N59508600820	
9N59100883113	9N59508603382	
9N59105818114	9N59508603446	
9N59106688168	9N59508603447	
9N59106693137	9N59508603448	
59107895241	59509647450	
59108169909	1N59758794030	
59108181635	1N59850202759	
9N59108389421	1N59850202768	
9N59108400148	59997135384	
9N59108496155	9G62102268748	
9N59108654510	9G62108180230	
59108908933	9G62205001448	
59150760129	66258600862	
2N59150762145	D19391+1	
59157135365	10TB18M	
59157135366	2114	
59158120126	34004071	
9N59158183391	36675-14	

Figure 19, provisioning level versus stock period, shows the comparison of the Vitro stock list, the EMEC APL based on the maintenance coding, and the ESO APL. The dotted line shows the estimated EMEC APL after adjustment was made to account for those 200 to 300 items which EMEC considered to be fabricated instead of ship stock candidates.

COST

Table 26 provides for comparison of the costs of the various stock lists investigated and generated during this program, both in Phase I and Phase II. As shown - the cost of the ESO generated APL was $69,704.00, with all parts being costed. The EMEC stock list was $67,370.00, with 95 parts lacking cost description. The Vitro stock list cost $89,957.00, with 82 Federal Stock Number designated parts and 343 manufacturer's number designated parts lacking cost description. Table 31 shows the cost analysis for the Vitro generated stock list. The first column indicates the stocking location. The second column indicates the cost per equipment of the stock aboard ship and support ship and at the depot. The last column indicates the total cost of stocking the system assuming that there are 84 ships carrying the AN/SPS-40 with 14 support ships with provisions as recommended by the generated stock lists. These costs do not consider any sharing of common parts in the system but rather that the AN/SPS-40 is the only piece of equipment in the Navy.

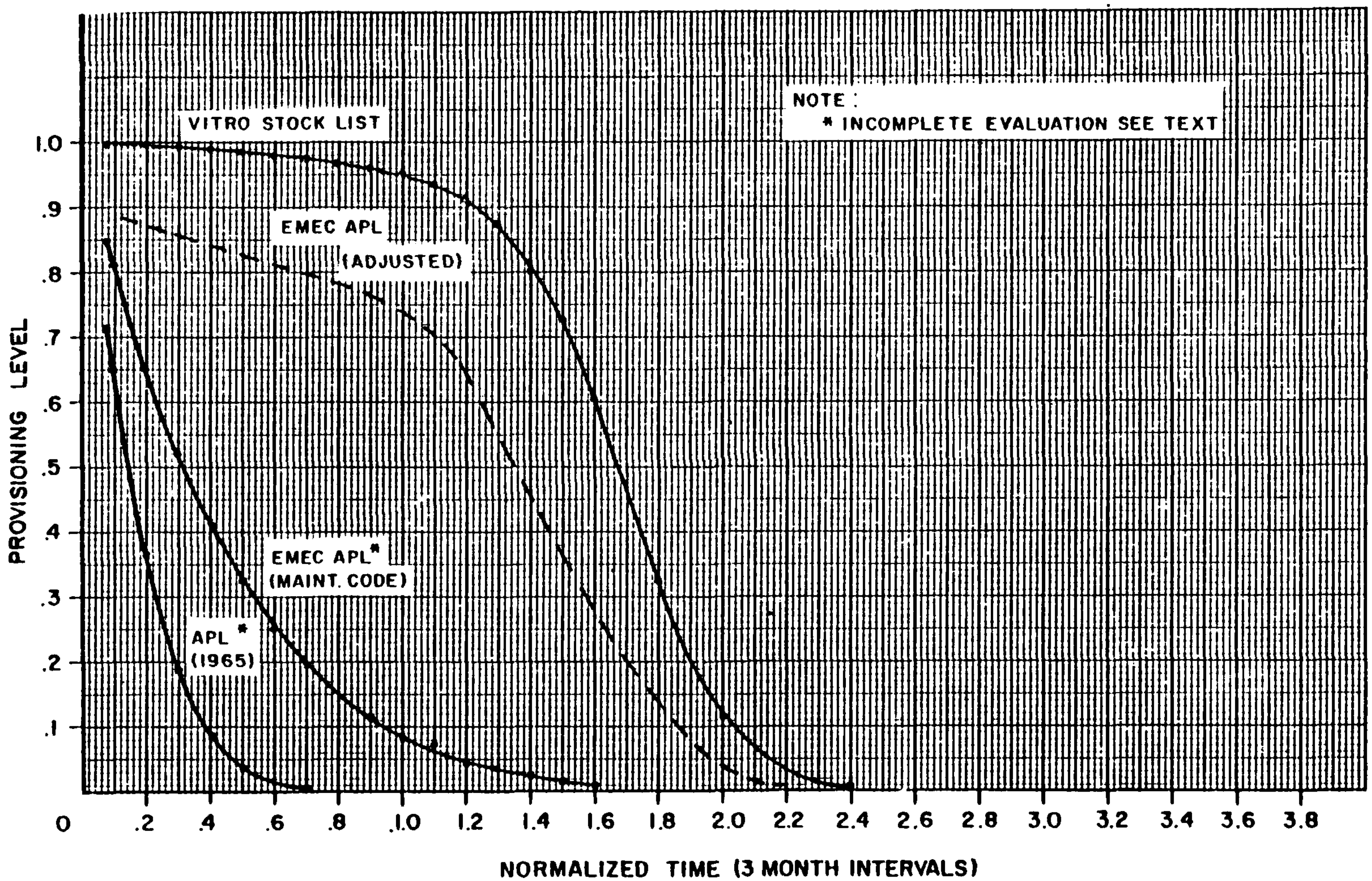


Figure 19. Vitro, EMEC, APL (1965) Comparison of Stock List Variation Graph

TABLE 31

SPARES COST ANALYSIS

LOCATION	COST PER EQUIPMENT	TOTAL COST
Ships (84)	$ 89,957.00	$ 7,556,388.00
Support Ship (14)	19,949.00	1,675,716.00
Depots (2)	11,697.00	982,522.00
Totals	$121,603.00	$10,214,626.00

Section XI
CONCLUSION AND RECOMMENDATIONS

Because the provisioning lists developed in this program are based on sound mathematical procedures, and because the rates used in this program are carefully calculated from equipment repair histories, it is felt that the results are the most accurate obtainable at present. Phase I results demonstrated that the procedure was properly sensitive to the control factors of part rates, part populations, stock policy and maintenance policy.

The provisioning procedure which handles a three echelon stocking problem has been shown through the various stock lists presented in this report to be capable of generating results. A major advantage of this procedure which is essential to logistics analysis is the program's flexibility. Flexibility has been illustrated by generating stock lists where all repairs were performed by the ship's electronic technician, where selected repairs were performed by the manufacturer, and where selected repairs were performed by a Navy maintenance repair facility. Each of these situations produced different stock lists. The program also has the flexibility of handling parts or assemblies as well as combinations of parts and assemblies. The program is capable of handling special cases such as maintaining minimum depth for all critical or essential items and limiting ship inventory costs by assigning low usage - high cost items to the support ship rather than stocking them aboard the ship. A further capability is added by the calculation print outs which furnish a means of making changes by hand to the

stock list without the requirement of a rerun on the computer.

Problems were encountered with the EMEC APL calculations using the three digit maintenance code as follows:

Installation echelon,

4 - for shipboard installation

D - for shore based repair facility

Maintenance echelon,

4 - for shipboard installation

D - for shore based repair facility

Z - for not repairable

Module

1 - Electronic Assembly - shipboard repair

2 - Electronic Assembly - repairable at shore based facility

3 - Electronic Assembly - non-repairable (throwaway)

4 - Part of Assembly - replaceable

5 - Part of Assembly - non-replaceable

6 - Part of Assembly - plug-in

The problem indicates that the above code does not describe the situation where items are installable by the ship, but are not to be considered because the items are to be fabricated on board. In order to efficiently use the maintenance code in conjunction with the provisioning program described by this study, the maintenance code should be expanded to describe this situation.

Although it was not demonstrated during this study, the procedure has the ability to generate stock lists tailored to a specific ship. For example an aircraft carrier with assembly maintenance capability would have a

stock list different from a destroyer without assembly maintenance capability. Appropriate stock lists per hull could likewise be generated depending on the type of assigned duty. For example, a ship in the Seventh Fleet could be given a higher provisioning level than a ship assigned picket duty off the continental United States with the capability of increasing allowed quantities if reassignment occurs. There is also the ability to stock the ships of the Seventh Fleet on the basis of a higher budget allowance than the picket ships. The provisioning procedure described in this report will handle the above constraints.

During this study the provisioning procedure has been applied to generating an APL type stock list. This procedure may be expanded to cover calculation of Coordinated Shipboard Allowance Lists (COSAL) which would exploit the advantages achieved in the AN/SPS-40 Radar program.

An immediate practical recommended application of the procedures generated during this study would be initial provisioning for new equipment. To illustrate such an application, assume that a new type of equipment consisting of 10,000 parts is being procured for the fleet. Figure 20 presents the major pertinent points in the program schedule. Item 1 indicates that this program has required 11 months of design and development. At the end of this period, preproduction testing and evaluation occurs as indicated by item 2. The contractor then begins the production run with the first equipment scheduled for delivery in 8 months or at the end of the 21st month as indicated by the schedule. The requirement for the parts list would be placed on the contractor to be available at the end of the 9th month. The parts list would consist of EAM cards where the entries would correspond to the parts list manual entries required as part of the documentation on the

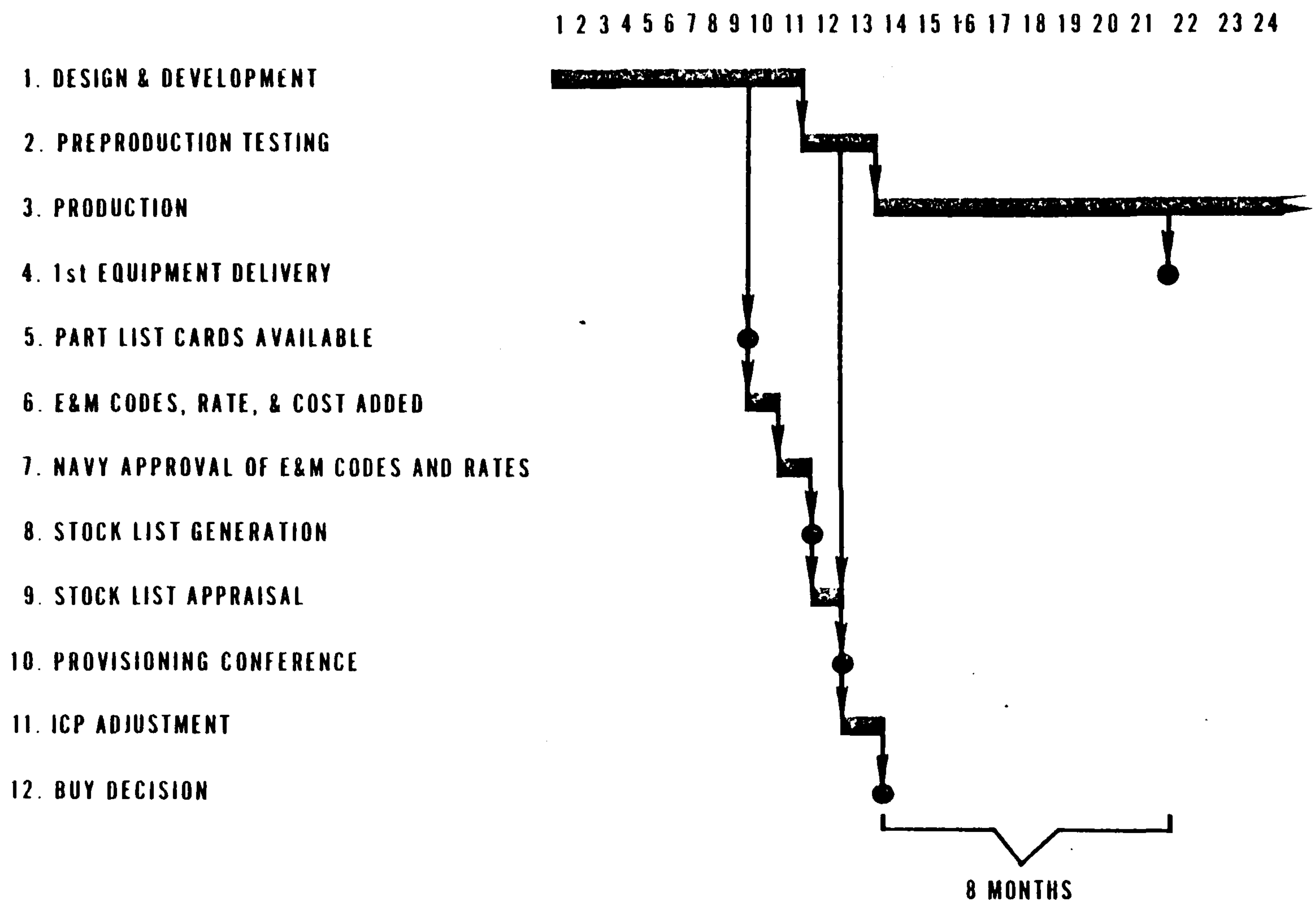


Figure 20. Example Schedule

equipment. The cards would contain, in a prescribed format the following information:

1. Federal Stock Number or manufacturer's number
2. short name or title
3. part reference designator or circuit symbol
4. a code to indicate if part is essential or non-essential to equipment operation which is the same as the essentiality codes presented earlier in this report
5. failure rate of part (will be available if reliability program was required)
6. maintenance code - a three digit Navy code
7. consumption rate to be used for determining stock quantities
8. weight (in pounds)
9. cube (in cubic feet)
10. cost

The above information requires 75 spaces on an EAM card which has a total of 80 spaces available. Military Specification Electronic Repair Parts Requirement, Procedures for Provisioning Documentation and Stock Numbering, MIL-E-173620 (SHIPS), now requires that the part number, cost, and essentiality of the parts be specified.

A major revision of MIL-E-173620 is recommended to require the contractor to include the remaining items listed above; to provide guidance for the contractor to develop the essentiality codes, maintenance codes and consumption rate (the remaining items are readily available to the contractor); to set forth the procedure for the assignment of the above codes; require the contractor to provide a complete list of parts with the above information on 80 column EAM Cards and submit a recommended stock list (range) and the total number of spare parts (depth) necessary to support the equipment

at a 90% provisioning level for a ninety-day period. This stock list should be determined in accordance with the Specification recommended in the following paragraph. and should include the total cost, weight and cube of the spare parts recommended for support.

A new specification should be developed detailing the procedures and methods to be used for determining an equipment Range and Depth Stock List that will supply the desired degree of confidence for a stated period of time. This specification should be developed in accordance with the statistical procedures used in this report and should be placed on the contractor as a mandatory requirement for all new equipment procurements. Print outs resulting from the use of this specification should include two parts lists, one in FSN/manufacturer's number order and another in circuit symbol order; Range and Depth stock list for an equipment; a stock list for a support ship; a stock list for a depot; and a listing by part type showing the total number of items required by the Navy to provision according to the quantities specified by the three stock lists. The contractor would retain a copy of the generated results and distribute copies to the Commander, Naval Ship Systems Command and the U. S. Navy Electronics Supply Office to use during the Parts Provisioning Conference.

One month or some pre-determined period of time would be allowed for each of the recipients to review and appraise the stock print outs. Comments and changes would be noted on the print outs. Since preproduction tests have been performed during the period of stock list development, the results of this testing would also be considered.

At the end of the review and appraisal period, a provisioning conference would be held where the comments and changes would be considered and

decisions made concerning necessary adjustments. It is believed that the above procedure which furnishes a prelimi:.ary stock list and information on all the parts will stimulate communications since areas where improvements are needed should be easier to determine when the entire picture is available for study. Further, in those areas where detailed investigations are required. the effort has been reduced to a problem of practical magnitude.

All of the provisioning information is now given to the Inventory Control Point. The Inventory Control point from this point on has the responsibility of producing the equipment APL, the ship COSAL, and buy quantities to support the new equipment in the system. The performance of these duties should be easier and clearer with the detailed information available after the provisioning conference. According to the schedule of figure 20 there remains eight months before the first equipment will be delivered for fleet use. More important, the decisions on procurement of spare parts can be made in time to be incorporated into the production contract.

Having used a procedure where all inputs and quantities used to derive the initial provisioning stock lists as specified, an analysis of the results over perhaps the first year of fleet use would provide a means for adjusting the equipment stock quantities as well as provide better data for the next future generation of equipments to be considered.

The above discussion is a suggested approach to the initial provisioning problem which fits into the present procedures and practices. The tools required are the provisioning procedure presented in this report and MIL-E-17362D (Ships) which would require revision to serve adequately. The advantage of this suggested approach to initial provisioning is the generation of a timely stock list based on sound mathematical principles and completely documental procedures including two government approval monitoring points.

(13)

TECHNIQUE FOR DETERMINING THE NUMBER OF SPARES WITH A PRECHOSEN PROBABILITY LEVEL

HERCHEL E. LYNCH AND RONALD S. MORRIS
USALMC INTERN TRAINING CENTER

DR. ROGER J. MCNICHOLS AND DR. DARRELL R. SHREVE
TEXAS A&M UNIVERSITY

The prediction of the number of spares or spare parts for a product or system is a problem, the importance of which has been recognized in almost every publication on Integrated Logistics Support planning and Systems Effectiveness both by the Department of Defense and by Industry. Many approaches to this problem have been presented and these are generally divided into two categories: first, those which contain some very confining and, perhaps, unrealistic assumptions such as sparing for the expected number of failures, assuming a constant failure rate and poisson process or sparing a system based on only the total operating time, and second, those approaches which require a computer simulation. The simulations range from the simple to the very complex and sophisticated models. However, both the simple and the complex require a computer program, a computer, and time on the computer, along with available personnel.

Some people realize the importance of selecting the proper sparing level and comprehend the multifaceted problem which such a selection involves. Many others, however, do not realize the long lasting and wide ranging ramifications of a sparing policy and its resultant effects on the key system parameters. The number of spares and the location of these spares for the system affects system availability, maintainability, and reliability provided replacement is permitted during the mission, as well as repair facility utilization and total system cost. When one recognizes all the implications of a particular sparing policy with regard to system parameters, he can easily see that consideration of the sparing policy is vital in the conceptual and trade-off analysis stage in the system's life cycle. In addition, it is difficult to understand how the many trade-off analysis which are necessary in the conceptual and design stages can be validly developed without consideration of the sparing policy. Thus, the selection of a sparing policy is not a problem which can be postponed until the system is produced and ready for use. This problem must be considered in the early stages of the system's life cycle with the other major system parameters. The primary reason why this has not been common practice to date is that a technique did not exist which could be utilized during the early stages of the life cycle and which did not require great amounts of time and money, and, perhaps, computer simulations.

This paper provides a simplified technique for determining the number of spares necessary for a system or groups of systems utilizing a prechosen probability level that sufficient spares will be available. This technique removes many of the restrictive, and, sometimes, unrealistic assumptions involved in previous methods. The basis for this technique is the fact that the density function of a sum of independent random variables approaches the normal density function, regardless of the type of density function each of the variables have. Using this fact, an asymptotic approximation proposed by Cox (3) and Barlow (2) and extensions by the authors, a technique is shown which will provide an estimate of the number of spares needed for the prechosen probability level; for any type of basic process density function, for any of the process sequences shown, and for single and multiple sparing policies. This is possible through utilization of the simplified tables, graph, and the step-by-step technique shown in this paper, along with calculations which are not complicated nor difficult and which do not require any knowledge of probability or statistical theory.

THE TECHNIQUE

This technique was derived using results obtained by Cox (3), and Barlow (2), which show that the time to the n^{th} event and the number of events which occur in a time interval, t, are both asymptotically normally distributed as n and t become infinite. These results were based on the central limit theorem and some previous results obtained by Feller (5).

In this paper the results obtained by Cox and Barlow have been applied to a sparing problem,(Figure 1, system class A and B1) and extensions have been made to provide models for many other types of system classes and sparing configurations. To apply this technique, the following restrictions are necessary:

1. The system must follow one of the process sequences and one of the sparing configurations shown, without deviation. (See Figures 1 and 2)
2. Only spare set can be required in any process cycle, where a process cycle is defined as the repeating sequence in a system, and must be required at the point in time shown in the process sequence.
3. All processes are independent.
4. The mean and variance of the density function of each process must remain constant over time.

The accuracy of the approximations shown in this paper depend upon the ratio of the sparing cycle time to the mean of the process cycle time and the shape of the basic process density function. It has been found that if this ratio is greater than 3 to 5 and if the basic process density functions are not badly skewed, the accuracy of the approximation is sufficient and, in most cases, better than the present methods.

Tenth Annual Reliability and Maintainability Conf. Annals of Assurance Sciences Anaheim Calif. 1971

Also, limits are shown for this approximation which provide an indication of the accuracy of the results.

STEPS TO APPLY TECHNIQUE

STEPS / **EXAMPLE**

FROM FEASIBILITY AND TRADE-OFF STUDIES.

1. *FROM INDIVIDUAL SYSTEM STUDIES:*
   A. Determine what processes the system undergoes during it's life cycle.
   — Example: Operation, Replacement, Test
   B. Draw system process sequence in terms of the actual operations performed on each system.
   — Example: Spare Required

Operation	Replacement	Test	Operation

2. *FROM SYSTEM SUPPORT STUDIES:*
   A. Determine number of systems, S, to be supported by the spare pool.
   — Example: $S = 6$
   B. Determine the time interval, T_R, that system R will be in the sparing cycle.
   — Example: $T_R = T_1 = T_2 = T_3 = T_4 = T_5 = T_6 = 600$ hrs.
   C. Determine the desired probability, $P_{1-\alpha}$, that the S systems will have enough spares for each system to undergo the process sequence shown for the time, T_R, during the sparing cycle.
   — Example: $P_{1-\alpha} \geq .92$

FROM THIS TECHNIQUE

3. *FROM FIGURE 1, 2, OR 3, DETERMINE THE FOLLOWING:*
   A. Using 1B relate the actual system process to sequence shown in Figure 1 and determine the system class.
   — Example: From Figure 1, System Class = C.3
   B. With the system class from 3A, relate actual operations performed on the system to the process numbers shown on Figure 1 and determine, μ_i, the mean and, σ_i^2, the variance of process i.

Operation	Replacement	Test
process 1	process 2	process 3
$\mu_1=40$	$\mu_2=10$	$\mu_3=12$
$\sigma_1^2=225$	$\sigma_2^2=25$	$\sigma_3^2=16$

   C. Using S from 2A and T_R from 2B, determine the sparing configuration type from Figure 2.
   — Example: From Figure 2, System Configuration = Type II
   D. Using $P_{1-\alpha}$ from 2C, determine Z_α from Figure 3.
   — Example: From Figure 3 with $P_{1-\alpha} = .92$, $Z_\alpha = 1.40$

4. *WITH FIGURE 4 OR 5, DETERMINE THE FOLLOWING:*
   A. Using system class from 3A and sparing configuration from 3C, find the equation for T using columns 1 and either column 2, 3, or 4 in Figure 5.
   — Example: From column 3, Figure 5, for system class C.3
   $T = S(T_1+\mu_2+\mu_3)$
   $T=600 \quad \mu_2=10 \quad \mu_3=12 \quad S=6$
   B. With this equation and the process parameters from 3B, solve for T.
   — Example: $T = 6(600 + 10 + 12) = 3732$
   C. Using system class from 3A, find equations for μ_C and σ_C^2 in column 5 and 6 in Figure 5. With the process parameters from 3B, solve for μ_C, and σ_C^2.
   — Example: From column 5, Figure 5, for system class C.3
   $\mu_C = \mu_1 + \mu_2 + \mu_3 = 40 + 10 + 12 = 62$
   D. From Figure 4, find values for K_1 and K_2.
   — Example: $\sigma_C^2 = \sigma_1^2 + \sigma_2^2 + \sigma_3^2 = 225 + 25 + 16 = 266$
   E. Using the values calculated in 4B, C, D and Z_α from 3D, solve for an approximate value for N(T) where

$$N(T) = \frac{T}{\mu_C} - SK_1 + Z_\alpha \sqrt{\frac{T\sigma_C^2}{\mu_C^3} + SK_2}$$

   Round N(T) upward to integer value, N',

   — Example:

$$K_1 = \frac{\mu_C^2 - \sigma_C^2}{2\mu_C^2} = \frac{62^2 - 266}{(2)(62)^2} = .465$$

$$K_2 = \frac{1}{12} + \frac{5\sigma_C^4}{4\mu_C^4} - \frac{2M_{C3}}{3\mu_C^3} = \frac{1}{12} + \frac{5(266)^2}{4(62)^4} - 0^* = .0892$$

   *Assume process densities are symetrical, $M_{C3} = 0$

$$N(T) = \frac{3732}{62} - 6(.465) + 1.40\sqrt{\frac{3732(266)}{(62)^3} + 6(.0892)}$$

$$= 60.439 \rightarrow 61 = N'$$

5. *FIND REVISED $P'_{1-\alpha}$ AS FOLLOWS:*
   A. Using the system class from 3A, the process parameters from 3B, N' from 4E, and equations in Figure 5, column 7 and 8, solve for μ_P and σ_P^2. Solve for μ_P' as follows:

$$\mu_P' = \mu_P + (S-1)(\mu_C)(K_1)$$

   — Example:
   $\mu_P = (N'+1)\mu_C - S\mu_2 - S\mu_3 = 62(62) - 6(10) - 6(12) = 3712$
   $\sigma_P^2 = (N'+1)\sigma_C^2 - S\sigma_2^2 - S\sigma_3^2 = 62(266) - 6(25) - 6(16) = 16{,}246$
   $\mu_P' = 3712 + (6-1)(62)(.465) = 3856$

B. Using μ_p' and σ_p^2 from 5A and T' as shown below, solve for the revised Z_α'

$T' = (6)(600) = 3600$

$$Z_\alpha' = \frac{\mu_p' - T'}{\sqrt{\sigma_p^2}} \qquad T' = \sum_{R=1}^{S} T_R$$

$$Z_\alpha' = (3856-3600) \div \sqrt{16{,}246} = 2.008$$

C. Using Z' from 5B and Figure 3, find revised $P_{1-\alpha}'$ which is the revised probability that enough spares will be available if N' spares are stocked.

$P_{1-\alpha}' = .978$ - Too High

D. If $P_{1-\alpha}'$ is not the desired value, modify N' and repeat steps 5B and C.

For N' = 60 $\quad Z_\alpha' = 1.535 \quad P_{1-\alpha}' = .94$

For N' = 59 $\quad Z_\alpha' = 1.053 \quad P_{1-\alpha}' = .86$

6. *FURTHER REVISIONS - RESULTS SHOULD BE CONSIDERED WITH LIMITS SHOWN BELOW FOR FURTHER REVISIONS IN $P_{1-\alpha}'$ AND N'.*

A. If the process density functions have a coefficient of variation, $\frac{\sigma}{\mu}$, greater than 1 and are skewed left, the results shown in this paper are optimistic, i.e., the actual probability, $P_{1-\alpha}'$ of having enough spares is less than obtained by this method.

B. If $\frac{\sigma}{\mu} = 1$, the density function is exponential and the actual probability of having enough spares, $P_{1-\alpha}'$, is less than obtained but the poisson can be used to refine the estimate.

C. If $\frac{\sigma}{\mu} < 1$ and the densities are skewed right, the actual probability of having enough spares is greater than obtained by this method.

D. If the process density functions are normally distributed, the results are fairly accurate.

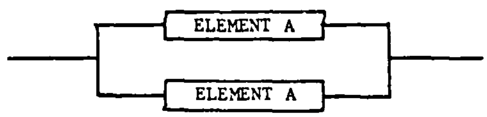
E. If some of the process densities are skewed left and some are skewed right, the results obtained by this method will closely approximate the actual situation.

7. *FINAL RESULTS - N' = NUMBER OF SPARES NECESSARY TO PROVIDE A PROBABILITY OF $P_{1-\alpha}$ THAT ENOUGH SPARES WILL BE AVAILABLE TO LAST FOR A TIME PERIOD, T = SUM OF T_R, IF S SYSTEMS ARE OPERATING AT T = 0.*

N' = 60 spares

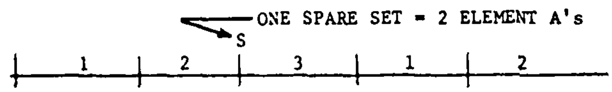
PARALLEL ELEMENT EXAMPLE

It should be noted that the technique can be applied to many types of redundant elements systems by properly defining the processes. An example of this may be the following type of system:



Assumptions:

1. Element A's are in active parallel redundancy.
2. Element A's are independent.
3. System is not repaired until both elements failed.
4. Both elements are replaced before system returns to operation.



Process 1 - time to first failure
Process 2 - time from first to second element failure
Process 3 - time to replace both elements

PREVIOUS ASSUMPTIONS AND METHODS

The previous methods for determining the number of spares required have some confining and perhaps, unrealistic, assumptions inherent in the methods. Some of these assumptions are as follows:

1. Sparing policy based on the average number of failures. If a system is spared for the average number of failures expected to occur, then roughly 50% of the time a spare is needed, a spare will not be available for the system.

2. Sparing policy based on operating time only (4) (6). The total operating time which occurs during a calendar time, if a system is undergoing failure and repair processes, is a stochastic variable following some statistical distribution. Some of the methods in the past have estimated the mean operating time which is expected to occur during a calendar time and used this value to determine the number of spares necessary. This assumption would give the same result as assumption number 1. It should be pointed out, however, that some systems actually operate and are spared correctly based only on operating time.

3. Sparing policy based on a constant failure rate (4) (6). The assumption on a constant failure rate for the failure process implies that the times to failure follow the negative exponential density function. If the times to failure follow the negative exponential density function, the mean of the density function must be equal to the standard deviation of the density function, which is not normally the result obtained in a testing program. A part

that is subject to wearout failure cannot have a constant failure rate. It should, also, be noted that if the times to failure do not follow the exponential density function, the failure rate is not the reciprocal of the mean of the density function.

4. Sparing policy based on the poisson process (4). The assumption that the number of failures which occur during a time period follows the poisson process implies that the times to failure follow the exponential density function. Thus, inherent in this utilization of the poisson process is, the assumption of a constant failure rate as discussed above.

5. Sparing policy based upon the results of a computer simulation (7). The use of a Monte Carlo simulation on a computer may be costly both in time and money. This coupled with the difficulty in verifying the accuracy of the simulation makes this approach undesirable, except in more complicated situations. Most of the simpler computer simulations will give no greater accuracy than the technique shown in this paper for the types of systems shown.

that, using this technique and Step 6B, a constant rate for the process cycle can be assumed and the results will be identical to prior techniques using a constant rate, one process and the poisson distribution for the number of failures.

There are many other possible usage for this technique, such as:

1. Given a certain number of spares, the probability of having enough spares can be found.
2. It can be used to verify the accuracy of the early predictions if the sparing configuration has been operating for a period of time and some results of the actual usage of spares are available.
3. It can be used to determine the effect of the sparing policy upon the system availability.
4. Given confidence intervals based on testing for the mean and variance of each process, pessimistic, expected and optimistic prediction of the number of spares needed can be accomplished.

CONCLUSIONS

It is felt that a person who has been struggling with the problems associated with choosing a sparing policy for a group of systems, either in the early or middle stages of the system's life cycle, can easily grasp the benefits from a simplified technique such as this one. The versatility of this technique has been adequately demonstrated.

The approximations involved in this procedure, i.e., the normal density function, will probably be less in error than the assumption of a constant rate. However, even with the assumption of the constant rate, except for two of the ten cases considered, the cases are difficult to solve. It should be noted

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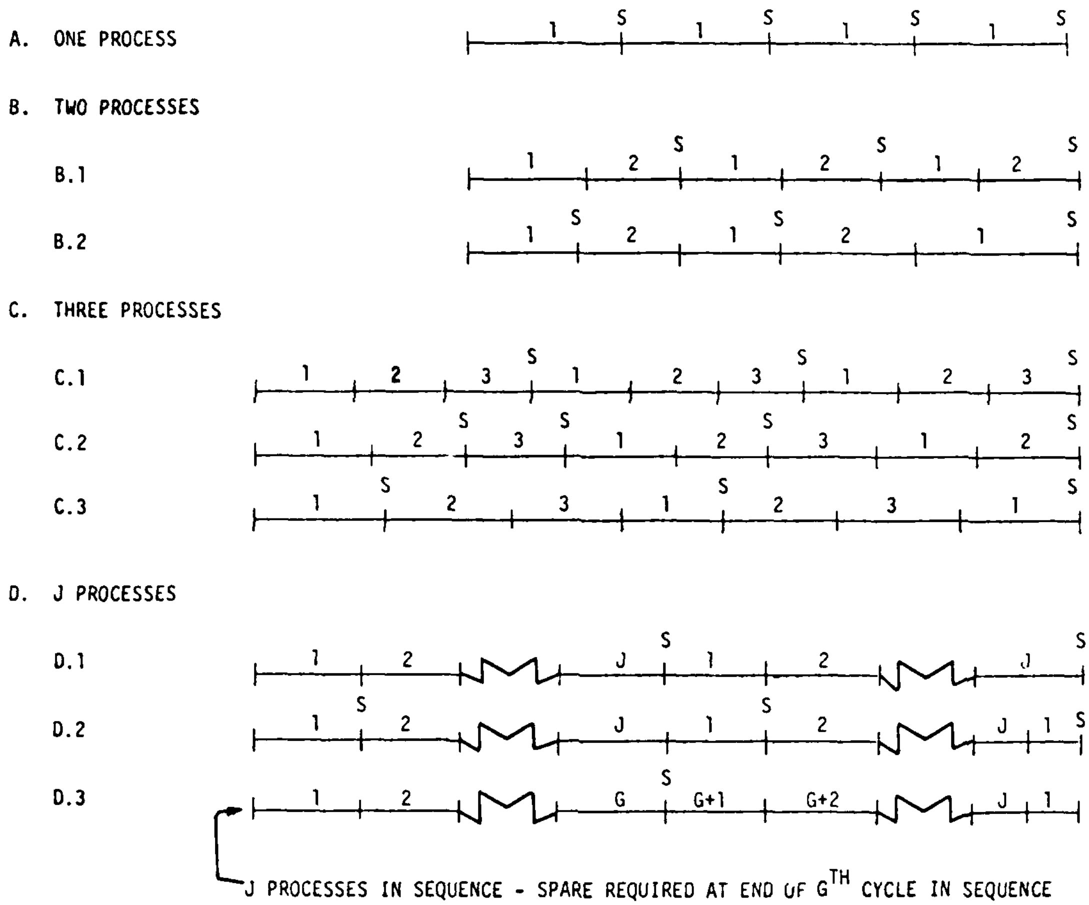
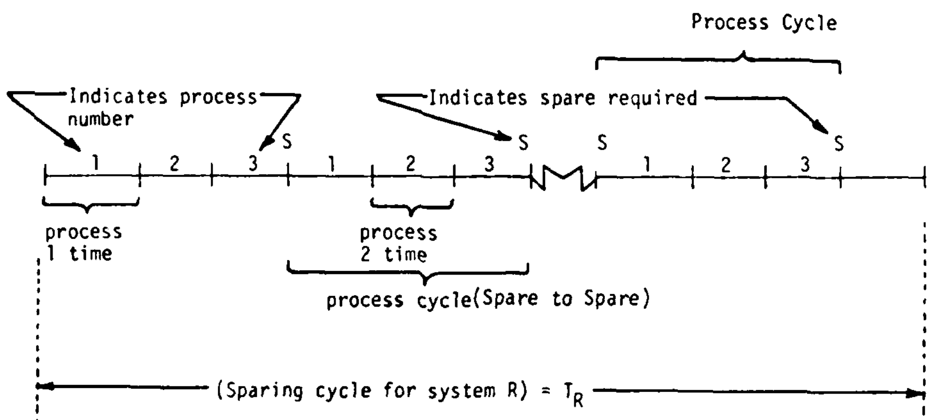
The above technique is the result of studies and research by the authors. The views expressed are those of the authors and do not necessarily reflect approval or endorsement by the Department of Defense or Texas A&M University.

APPENDIX A

FIGURE 1 - SYSTEM CLASS



LEGEND FOR FIGURE 1



THE SYSTEM PROCESS SEQUENCE AND WHERE THE SPARE SET IS REQUIRED DETERMINES THE SYSTEM CLASS

FIGURE 2 - SPARING CONFIGURATION TYPE*

I Single System $S = 1$
Sparing Cycle $= T_1$

II Multiple systems - each sequence is identical
Number of Systems = S
Sparing cycle of all systems are equal to T_1

III Multiple systems - each system sequence is identical
Number of Systems = S
Sparing cycle of each system = T_R and may be different

* The system configuration identifies how many systems, S, will receive spares from the spare pool and the length of time, T_R, each system will be in the process sequence during the sparing cycle.

FIGURE 3 - VALUES OF Z_α AND $P_{1-\alpha}$

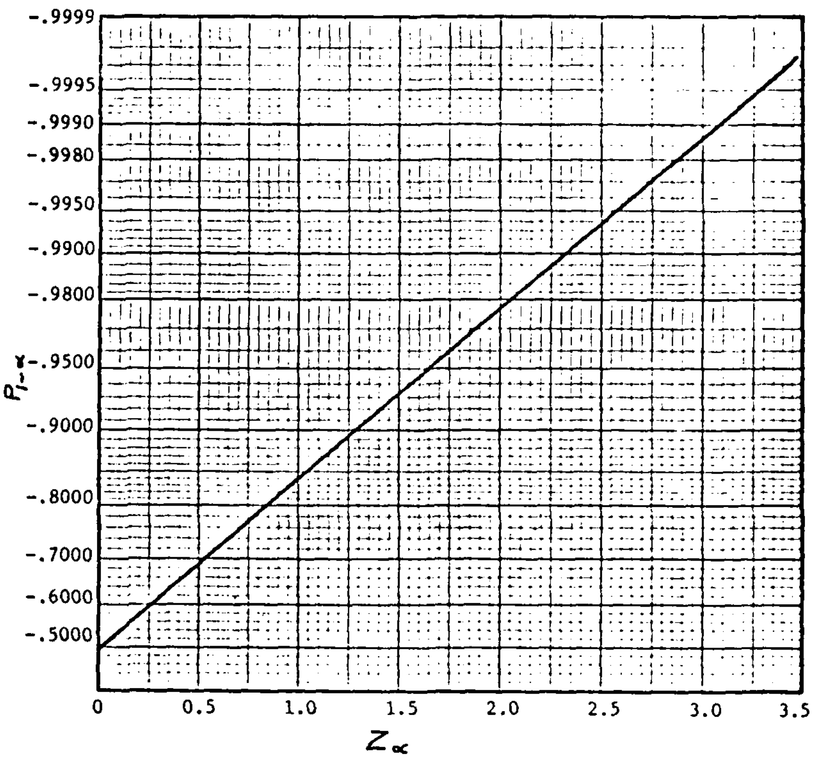


FIGURE 4 - K_1 AND K_2 FACTORS

K_1 FACTOR

Using μ_c and σ_c^2 from column 5 and 6, Figure 5, solve for:

$$K_1 = \frac{\mu_c^2 - \sigma_c^2}{2\mu_c^2}$$

NOTE: A. if $\sigma_c < \mu_c$ max value of $K_1 = +\frac{1}{2}$
min value of $K_1 = 0$

B. if $\sigma_c = \mu_c$ $K_1 = 0$

K_2 FACTOR

$$K_2 = \frac{1}{12} + \frac{5\sigma_c^4}{4\mu_c^4} - \frac{2M_{c3}}{3\mu_c^3}$$

where M_{c3} = third moment of the process cycle time density function about its mean = sum of third mements of the process time density functions about their mean.

C. If the process times are distributed according to the gamma ($\alpha > 1$), normal, Weibull ($\beta > 1$) or is at least two processes, each following the exponential, then A above is true, i.e., the convolution for the process cycle time has an increasing rate and $\sigma_c < \mu_c$.

D. If there is only one process and the times are distributed according to the exponential, then B above is true, i.e., the exponential density has a constant rate.

E. If there are two or more processes in the cycle and each has certain forms of the Gamma or Weibull, then B may be true, i.e., the convolution for the process cycle time may have a constant rate, however, A, B, or C may be the case.

If the density function is symetrical, then $M_{c3} = 0$ otherwise
$M_{c3} = E\,(t_i - \mu_i)^3$ where t_i = variable
μ_i = mean

FIGURE 5 - VALUES OF T, μ_c, σ_c^2, μ_p, and σ_p^2

SYSTEM CLASS See Step 3A	T - See Step 4A SPARING CONFIGURATION TYPE			USE FOR STEP 4C	USE FOR STEP 5A	
	I	II	III	μ_c (5) σ_c^2 (6)	μ_p	σ_p^2
(1)	(2)	(3)	(4)		(7)	(8)
A	T_1	ST_1	$\sum_{R=1}^{S} T_R$	μ_1 σ_1^2	$(N'+1)\mu_c$	$(N'+1)\sigma_c^2$
B.1	T_1	ST_1	$\sum_{R=1}^{S} T_R$	$\mu_1+\mu_2$ $\sigma_1^2+\sigma_2^2$	$(N'+1)\mu_c$	$(N'+1)\sigma_c^2$
B.2	$T_1+\mu_2$	$S(T_1+\mu_2)$	$\sum_{R=1}^{S} T_R + S\mu_2$	$\mu_1+\mu_2$ $\sigma_1^2+\sigma_2^2$	$(N'+1)\mu_c - S\mu_2$	$(N'+1)\sigma_c^2 - S\sigma_2^2$
C.1	T_1	ST_1	$\sum_{R=1}^{S} T_R$	$\mu_1+\mu_2+\mu_3$ $\sigma_1^2+\sigma_2^2+\sigma_3^2$	$(N'+1)\mu_c$	$(N'+1)\sigma_c^2$
C.2	$T_1+\mu_3$	$S(T_1+\mu_3)$	$\sum_{R=1}^{S} T_R + S\mu_3$	$\mu_1+\mu_2+\mu_3$ $\sigma_1^2+\sigma_2^2+\sigma_3^2$	$(N'+1)\mu_c - S\mu_3$	$(N'+1)\sigma_c^2 - S\sigma_3^2$
C.3	$T_1+\mu_2+\mu_3$	$S(T_1+\mu_2+\mu_3)$	$\sum_{R=1}^{S} T_R+S(\mu_1+\mu_2)$	$\mu_1+\mu_2+\mu_3$ $\sigma_1^2+\sigma_2^2+\sigma_3^2$	$(N'+1)\mu_c-S\mu_2-S\mu_3$	$(N'+1)\sigma_c^2-S\sigma_2^2-S\sigma_3^2$
D.1	T_1	ST_1	$\sum_{R=1}^{S} T_R$	$\sum_{i=1}^{J}\mu_i$ $\sum_{i=1}^{J}\sigma_i^2$	$(N'+1)\mu_c$	$(N'+1)\sigma_c^2$
D.2	$T_1+\sum_{i=2}^{J}\mu_i$	$S(T_1+\sum_{i=2}^{J}\mu_i)$	$\sum_{R=1}^{S} T_R+S\sum_{i=2}^{J}\mu_i$	$\sum_{i=1}^{J}\mu_i$ $\sum_{i=1}^{J}\sigma_i^2$	$(N'+1)\mu_c-S\sum_{i=2}^{J}\mu_i$	$(N'+1)\sigma_c^2-S\sum_{i=2}^{J}\sigma_i^2$
D.3	$T_1+\sum_{i=g+1}^{J}\mu_i$	$S(T_1+\sum_{i=g+1}^{J}\mu_i)$	$\sum_{R=1}^{S} T_R+S\sum_{i=g+1}^{J}\mu_i$	$\sum_{i=1}^{J=}\mu_i$ $\sum_{i=1}^{J}\sigma_i^2$	$(N'+1)\mu_c-S\sum_{i=g+1}^{J}\mu_i$	$(N'+1)\sigma_c^2-S\sum_{i=g+1}^{J}\sigma_i^2$

LEGEND S = NUMBER OF SYSTEMS T_R = SPARING CYCLE TIME INTERVAL

Naval Research Logistics Quarterly, vol 17 Dec. 19
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A METHODOLOGY FOR ESTIMATING EXPECTED USAGE OF REPAIR PARTS WITH APPLICATION TO PARTS WITH NO USAGE HISTORY

Sheldon E. Haber and Rosedith Sitgreaves*

The George Washington University
School of Engineering and Applied Science
Institute for Management Science and Engineering

ABSTRACT

In this paper a model is presented which focuses on the difficult problem of predicting demands for items with extremely low usage rates. These form the bulk of repair parts in military systems. The basic notion underlying the model is the pooling of usage data for common design items with movement for the purpose of estimating usage rates for similar items which have *shown no movement.*

A unique feature of the model is that it also makes possible the estimation of usage rates for items newly introduced into a system for which no previous usage history is available.

0. INTRODUCTION

The problem of predicting demands for individual repair parts in military inventory systems has received much attention over the last two decades. This problem is a complicated one because of the sporadic nature of demands for military repair parts. For most repair parts, no demands are registered over long periods of time and when items are demanded, they are generally demanded only once or twice. This fact has now been documented by *many usage studies* † *and is once again documented* in this study. To illustrate the nature of the demand problem under consideration, usage data for 61 submarine patrols are shown in Table 1. As may be seen from the first entry in the table, no usage

TABLE 1. Distribution of 25,138 Different Repair Parts by the Number of Patrols in Which They Were Demanded

Number of patrols	Frequency of different parts
0	21,597
1	1,776
2	673
3	333
4	199
5	134
6	96
7	81
8	62
9	32
10	28
11-61	127
Total	25,138

*Columbia University.

†For a review of this literature, see Henry Solomon, "A Summary of Logistics Research Project's Experience With Problems of Demand Prediction," in [1].

was recorded for the vast majority of items, i.e., the vast majority of items was not demanded in any one of the 61 patrols. Of those that were demanded, one-half were demanded in exactly one patrol. Thus for most repair parts with usage, the problem of estimating usage rates is a difficult one. This difficulty is compounded by an order of magnitude for the bulk of the items whose usage history shows zero units used.

In this paper we will be concerned with the estimation of expected usage of repair parts for the purpose of computing shipboard allowance lists. A shipboard allowance list is defined as the range and depth of repair parts to be stocked aboard ship to meet uncertain demands. The range of repair parts refers to the number of different items to be stocked. The depth refers to the number of units stocked of an item.

Given that repair part usage is sporadic, several demand prediction strategies are available. The most widely practiced approach is that of employing usage estimates provided by technicians, i.e., supply personnel responsible for provisioning of repair parts. In practice, these have been found to be conservative and lead to relatively expensive stockage lists. Such conservatism, however, is preferred to a much more extreme approach which might assign a zero usage estimate to a repair part until positive usage is experienced. The difficulty with this latter approach is that many repair parts are only one-time movers. Failure to have an adequate quantity of stock aboard ship or in the supply system prior to the first demand can thus lead to a large range of shortages and an unsatisfactory level of readiness.

Another approach that has been utilized to estimate usage of slow moving items is exponential smoothing [2]. In this procedure, a technician's usage estimate is generally employed as an initial estimate. Hence, the initial procurement for repair parts will be based solely on the technician's estimate and will thus be subject to the limitation already noted.*

One procedure for the problem at hand is to utilize information not directly pertaining to the repair part being considered.† This is the approach of this paper. The information used pertains to the class of repair parts of which the given repair part is a member. It is assumed that usage data are available for the repair part class and that some of the items in that class have shown movement in the past. The advantage of this procedure is that it permits the pooling of demands where they have occurred and the use of this information for making positive usage estimates for items for which zero usage has been recorded. The procedure also provides an expected usage estimate for new items being introduced into the inventory system for which no usage history is available.

The criterion used in this study for defining repair part class is that of *nomenclature* of which resistor, washer, motor, and valve are examples. It should be noted that within a given class, estimated usage rates will vary depending on the design, environment, location, etc., of each part. The usefulness of partitioning by nomenclature rests on the assumption that variations in usage rates within a given nomenclature class will be less than that among classes. In this case, the stratification of repair items should reduce the variance of the estimates vis-a-vis the alternative of not distinguishing items by nomenclature class.

In the next section we present a theoretical model for estimating expected usage of repair parts, in particular repair parts with no usage history. Following a description of the model, goodness-of-fit

*Furthermore, for zero movers this procedure will quickly lead to usage estimates that are indistinguishable from zero.

†A model of this type, which uses information pertaining to the failure behavior of the part's parent component, is described in [5].

tests are applied. In the final section, the model is evaluated by developing alternative allowance lists and comparing these lists against actual submarine usage data.

1. THE PROBABILITY MODEL

We consider a class C of items defined, for example, in terms of nomenclature. Let part I be any item classified as belonging to class C, and let $y_I = 0, 1, 2, \ldots$, represent the total *quantity of units* demanded for part I is a specified time period T, say a total of T patrols.* We consider a probability model in which the quantity y for a given part (more precisely, y_I) is a random variable with a Poisson distribution given by

$$p(y|\theta) = \frac{e^{-T\theta}(T\theta)^y}{y!}, \tag{1}$$

where θ (again more precisely, θ_I) is the parameter of the Poisson distribution of demands for item I *in a unit time period, in our case, a single patrol.*† Note that θ is thus the expected number of units demanded for part I in a patrol. It is assumed further that demands for part I in non-overlapping periods of time are independently distributed.

Our problem is to estimate θ for any item I classified as belonging to class C. We distinguish two cases. In the first case, we are concerned with estimating θ for installed items for which usage data, i.e., *y values are available.* As *indicated* earlier, the problem here is complicated by the fact that for the majority of items no usage is recorded, i.e., the observed y values during T time periods are zero. In the second case, we would like to estimate θ, that is, the expected usage, for items classified as belonging to class C, but being installed for the first time. In this case, no y values, zero or otherwise, are available.

In *both cases, it seems intuitively reasonable to assume* that positive usage data for some members of the class should be useful in determining estimates of the θ values for the remaining members. We formalize this by postulating that θ is itself a random variable with a probability distribution over all items in the class C. We then use standard theory to obtain the desired estimates for both cases mentioned above.

In general, *if $p(\theta)$ denotes the probability distribution of θ* in the class C, and $p(y, \theta)$ the joint distribution of y and θ, then

$$\begin{aligned} p(y, \theta) &= p(y|\theta) \cdot p(\theta) \\ &= p(\theta|y) \cdot p(y), \end{aligned} \tag{2}$$

where $p(y)$ denotes the unconditional distribution of y values for the class C, and $p(\theta|y)$ the conditional distribution of θ, given y.** In the first case mentioned above in which the observed $y = 0, 1, 2, \ldots$, we estimate θ by

$$\bar{\theta} = E(\theta|y)$$

from the conditional distribution of θ. In the second case, when y values do not exist, we estimate θ

---

*For simplicity we do not distinguish between the random variable y and the values which it assumes. Throughout, we also use the symbol $p(\ )$ to represent different probability distributions.

†The subscript I has been omitted from y and θ to reduce the subscripts necessary to indicate a constant.

**In Bayesian terms, $p(\theta)$ is the prior distribution, and $p(\theta|y)$ the posterior distribution.

by the value $E(\theta)$, the unconditional expected value of θ. In this latter case, the estimate of θ is the same for all new items in the class C, while in the former case θ varies for each item in class C depending on its y value.

In considering possible distributions for θ, we assume that the class C can be extended in such a way that θ can be treated as a continuous variable with a probability density function. The preponderance of y values of zero in most classes led us to consider densities whose maximum value occurs for $\theta = 0$. We examined first the exponential density

$$p(\theta) = \frac{1}{\beta} e^{-\frac{\theta}{\beta}} \text{ for } 0 < \theta < \infty,$$

but resulting calculations did not give evidence of a good fit. A natural extension, which because of its mathematical properties seemed particularly appropriate for the distribution of a Poisson parameter, is a two-parameter gamma distribution. Accordingly, we assumed that

$$(3) \qquad p(\theta|\alpha, \beta) = \left(\frac{\alpha}{\beta}\right)^{\alpha} \frac{\theta^{\alpha-1} e^{-\frac{\alpha}{\beta}\theta}}{\Gamma(\alpha)} \qquad \text{for } 0 < \theta < \infty,$$

with $\alpha, \beta > 0$. For any value of $\alpha < 1$, this function is infinite at $\theta = 0$, and is monotonically decreasing as θ increases from 0 to ∞.

From (1) and (3), Eq. (2) can be written specifically as

$$(4) \quad p(y, \theta|\alpha, \beta) = p(y|\theta) \cdot p(\theta|\alpha, \beta) = \frac{\alpha^{\alpha} \theta^{\alpha+y-1} e^{-\frac{(\alpha+T\beta)}{\beta}\theta} T^y}{\beta^{\alpha} \Gamma(\alpha) y!}$$

$$= \left(\frac{\alpha+T\beta}{\beta}\right)^{\alpha+y} \frac{\theta^{\alpha+y-1} e^{-\frac{(\alpha+T\beta)}{\beta}\theta}}{\Gamma(\alpha+y)} \cdot \frac{\Gamma(\alpha+y)}{\Gamma(\alpha) y!} \frac{\alpha^{\alpha} (T\beta)^y}{(\alpha+T\beta)^{\alpha+y}}$$

$$= p(\theta|y, \alpha, \beta) \cdot p(y|\alpha, \beta).$$

Thus, the conditional distribution of θ, given y, also has the form of a gamma distribution, while the unconditional distribution of y for the class C is a negative binomial.

From (4) and (3), we find

$$(5) \qquad E(\theta|y) = \frac{T\beta}{\alpha + T\beta} \cdot \frac{\alpha + y}{T},$$

for the first case where y values are available while

$$(6) \qquad E(\theta) = \beta,$$

for the second case where items are being installed for the first time and there are no y values.

For any item in class C with an observed y value, we now have from (5) an estimator for the expected usage for the item, namely $\hat{\theta}$. The estimator can be evaluated for every y value, including zero, if we

have values for the two parameters α and β. We estimate these parameters from the observed set of y values for the class C, treating these values as a set of independent observations from a negative binomial distribution with mean value $T\beta$ and with variance $T\beta\left(1+\frac{T\beta}{\alpha}\right)$.

Let $y_1, y_2, \ldots, y_n$ be the observed y values for the n items $l=1, 2, \ldots, n$ in class C. From the data we estimate the mean and variance by

$$\bar{y}=\frac{1}{n}\sum_{i=1}^{n} y_i \text{ and}$$

$$V=\frac{1}{n-1}\sum_{i=1}^{n}(y_i-\bar{y})^2, \text{ respectively.}$$

We estimate $T\beta$ by $\bar{y}$ so that

$$\hat{\beta}=\frac{\bar{y}}{T}.$$

In estimating α, we use the method of moments since this is relatively simple and straightforward. Since the variance of y is $T\beta\left(1+\frac{T\beta}{\alpha}\right)$, we estimated the variance as

$$T\hat{\beta}\left(1+\frac{T\hat{\beta}}{\hat{\alpha}}\right) \text{ and with } \hat{\beta}=\frac{\bar{y}}{T}, \text{ from above,}$$

obtain

$$\hat{\alpha}=\frac{\bar{y}^2}{V-\bar{y}}.$$

Hence, in the case where an observed y value is available for a given item, the desired estimate of θ for the item is

$$\tilde{\theta}=\frac{T\hat{\beta}}{\hat{\alpha}+T\hat{\beta}}\cdot\frac{\hat{\alpha}+y}{T}.$$

and in particular when $y=0$, we have

$$\tilde{\theta}=\frac{\hat{\alpha}\hat{\beta}}{\hat{\alpha}+T\hat{\beta}}>0.$$

For $y>0$, as T becomes large, the quantity $\frac{T\hat{\beta}}{\hat{\alpha}+T\hat{\beta}}$ approaches the value 1, and $\tilde{\theta}$ approaches $\frac{y}{T}$.

In the case of new items being introduced into the inventory system, the estimated expected usage for the item is given by $\hat{\beta}=\frac{y}{t}$ where it is seen from (6) that β is the expected value of θ for the repair part class describing the new item.

2. EVALUATION OF GOODNESS-OF-FIT

In the preceding section, we assumed that the distribution of expected usage for items in a given class C was a two-parameter gamma distribution. This, in turn, led to a negative binomial distribution of demands for items in the class. In this section, we examine the goodness-of-fit of the model just described. It will be recalled that a similar assessment of the earlier exponential model led to its rejection. The purpose here is not an exact test of a particular hypothesis, but rather to determine the reasonableness of the model finally adopted. An additional test of the model in an inventory context is provided in the next section.

In examining the goodness-of-fit of the model, a large number of repair part classes were defined on the basis of nomenclature and for each class $\hat{\alpha}$ and $\hat{\beta}$ were computed from the available data. Having obtained these estimates, theoretical negative binomial distributions of demands for items in each class were calculated and compared with the actual distributions of y values. The comparison of the actual and theoretical frequencies for each class was made by computing the value of chi-square as an index of goodness-of-fit. Again, it was not the purpose to use each of the chi-squares as a rigorous test of the corresponding null hypothesis. The intent was to utilize the chi-squares and the associated significance probabilities as the basis for assessing the appropriateness of the model.

In evaluating the results, the following points should be kept in mind. First, because of the vagaries of reporting, no model may provide a satisfactory fit to the data. For example, extremely large y values may be expected as a result of mispunched data or stockpiling of material. Additionally, demands for repair parts are often for even numbered quantities. The prevalence of demands for even quantities may be seen from the distribution of y values for 61 patrols shown in Table 2.

TABLE 2. Distribution of 25,138 Different Repair Parts By the Total Quantity of Units Demanded During 61 Patrols

Total demand quantity [a]	No. of different repair parts	Total demand quantity [a]	No. of different repair parts
3	249	14	26
4	249	15	28
5	121	16	27
6	124	17	9
7	86	18	20
8	97	19	14
9	58	20	38
10	61	21	17
11	36	22	13
12	57	23	10
13	29	24	18

[a] For the total sample of 25,138 different repair parts, items with a total demand quantity of 0, 1, 2 units during 61 patrols were 21,597, 1,027, and 495, respectively. The number of different repair parts with a total demand quantity of 25 or more was 632.

Second, the nature of the chi-square statistic itself is such that relatively small differences between observed and expected *relative* frequencies will lead to large chi-squares if the sample is large. For the purpose of evaluating goodness-of-fit within a demand prediction context, this relation is an important one.

In performing the goodness-of-fit computations, we were able to determine the significance of chi-square for 54 classes of repair parts containing 18,347 different parts. For the repair classes ex-

amined, no correction was made for the phenomenon of even quantity demands. It was possible, however, to correct for the presence of outliers. Items in a repair part class were treated as outliers and eliminated if the smallest y value omitted was large relative to the largest y value included. In almost all cases the outliers had a very low unit price, or a high total installed population, or large individual demand quantities, or a combination of these characteristics. For example, in the repair part class "filters" containing 370 different filters, one filter had a total demand quantity of 320 units – all units of the item being demanded in a single transaction. Of the 18,847 parts in the sample, this item and 37 other repair parts were eliminated as outliers.*

The results of the goodness-of-fit computations, after elimination of the 38 items considered to be outliers, are shown in Table 3.

TABLE 3. Summary of Chi-Square Computations

Different repair parts in class	Number of repair part classes	Number of classes with poor fit at	
		0.05 level	0.01 level
100 or Less	10	1	1
101 to 499	30	7	0
500 and Over	14	6	3
Total	54	14	4

Over all classes, poor fits were obtained for but 4 and 14 of the 54 repair part classes at the 0.01 and 0.05 levels, respectively. As may be seen from Table 3, the incidence of poor fits increased as the number of repair parts in a class increased. In interpreting the results of Table 3, the earlier observation that where the number of items in a class is large, discrepancies between observed and expected relative frequencies may still be small, should be recalled. Indeed, this was the case for almost all of the repair part classes where the chi-square was larger than expected on the basis of chance alone.

3. FURTHER ASSESSMENT OF THE MODEL

In addition to examining the goodness-of-fit of the model, shipboard allowance lists were computed using as input the demand prediction model previously described. These lists were then compared with an allowance list utilizing technicians' usage estimates, both in terms of dollar investment in stock and shortage counts. The purpose of this evaluation was (1) to simulate the performance of the model in the environment for which it was designed, and (2) to determine whether differentiating repair parts by nomenclature class represented an improvement over a simpler approach of grouping all items into a single class.

The data base for an initial test consisted of 61 patrols of usage history. The items included in this initial test fall into the first category of repair parts distinguished in this paper, i.e., items for which usage data are available including data for items with "usage" of zero units. Employing past usage

*The total of 38 outliers was concentrated in 16 repair part classes. No class with 100 or fewer different repair parts contained any outliers; 10 of the 30 classes with 101 to 499 parts contained outliers; while the remaining 6 classes with outliers came from the 14 classes with 500 or more parts. This distribution is not inconsistent with the plausible hypothesis that the probability of observing an outlier in a given class increases with the number of different parts in the class.

data for the 61 patrols and the demand prediction model, usage rates were computed for each repair part under two procedures: (1) different $\hat{\alpha}$ and $\hat{\beta}$ were computed for each nomenclature repair part class (Model II A), and (2) a single value of $\hat{\alpha}$ and $\hat{\beta}$ was used for all repair parts regardless of nomenclature class (Model II B).* Allowance list quantities were then computed for these procedures and the one incorporating technicians' usage estimates (Model I) using the inventory model described in [4]. In all cases the inventory model was used with the same parameters. Thus, the only difference in the computation of the allowance lists was the technique used for deriving usage estimates. The allowance list quantities were next compared against usage data during a subsequent 21 patrols. The data for these patrols were not used in the initial calculation of usage rates. After each new patrol the model allowance list quantities were updated. No updating procedure was available for the quantities computed using the technicians' estimates.

Summary data describing the allowance list computed for items with previous usage history are shown in Table 4. As may be seen, Model I was about three times as expensive as the other two models. In terms of depth or number of units stocked, Model I stocked almost five times as many units as the other models. In terms of range or number of different items stocked, both Models I and II A stocked more items than Model II B. Thus, one effect of distinguishing among repair part classes on the basis of nomenclature was to increase the range of repair parts stocked by the model.

TABLE 4. Range, Depth, and Dollar Value of Investment: Items With Previous Usage History [a]

Model	Range of items stocked [b]	Depth of units stocked [c]	Dollar value
I	18.6	112.3	2,703.1
II A	18.9	25.4	960.4
II B	16.0	22.5	854.7

[a] Averages for 21 patrols. All figures in thousands.
[b] Number of different repair parts stocked.
[c] Number of units stocked.

The average range or number of different items with a shortage and the average depth or number of units short per patrol are shown in the first and second column, respectively, of Table 5. It should be remarked that the latter measure is not without difficulty of interpretation due to the problem of mix of different units of measure among items, e.g., some items are measured in feet while others are in units of "each." For the sake of completeness, however, this measure is included as an alternative measure of performance.

In Table 5, shortage counts are provided separately for items not stocked and for items stocked. These two categories of stock are distinguished since items in the former category tend to be "not carried" over successive patrols. From Table 5, it is seen that for items stocked, there were on the average 19.5 and 23.1 different items with a shortage per patrol for Models I and II A, respectively. Over all items with a shortage, the total number of units short averaged 172.3 and 225.0. In terms of the number of units short per item short, Model I averaged 8.8 (172.3 ÷ 19.5) as compared to 9.7 (225.0 ÷ 23.1) for Model II A.

*For Model II B, $\hat{\alpha} = 0.00787$ and $\hat{\beta} = 0.0241$.

TABLE 5. Shortage Counts: Items With Previous Usage History[a]

Items	Shortages: All items	
	Range[b]	Depth[c]
Not stocked:		
Model I	2.5 (2.2)	6.8 (13.3)
Model II A	3.0 (2.8)	4.8 (5.1)
Model II B	6.7 (4.0)	12.1 (8.8)
Stocked:		
Model I	19.5 (12.8)	172.3 (132.2)
Model II A	23.1 (14.3)	225.0 (196.3)
Model II B	21.2 (13.8)	219.6 (195.0)

[a] Averages for 21 patrols. Standard deviation in parentheses.
[b] Number of different repair parts with shortages.
[c] Number of units short over all repair parts.

A second test similar to the one described above was performed for 4,094 items which were treated as new items being introduced into the system. It should be noted that none of these items were included in the previous test. Following the model, in developing usage rates for this test, only the parameter β was used. For Model II A, β varied from class to class; for Model II B, β was invariant for all items. In each case, the β value used was the same β value employed in the first test. Thus this second test was a more stringent one in that not only were inventory quantities matched against unknown future usage (for 35 patrols), but in estimating item demand distributions the input data were from a completely different set of repair parts.

Summary figures describing the allowance lists and shortage counts for items which were treated as new items being introduced into the system are shown in Tables 6 and 7, respectively. The format of these tables is the same as for Tables 4 and 5.

TABLE 6. Range, Depth, and Dollar Value of Investment: Items With No Previous Usage History[a]

Model	Range of items stocked[b]	Depth of units stocked[c]	Dollar value
I	3.9	18.9	450.2
II A	3.7	4.4	231.8
II B	3.2	3.8	145.2

[a] Averages for 35 patrols. All figures in thousands.
[b] Number of different repair parts stocked.
[c] Number of units stocked.

From Table 6, one notes that as in the case for items with previous usage history, Model I was the most expensive one. The additional dollar value of investment for Model I was once again accounted for by the large number of units stocked, given that an item was stocked. Likewise, the range of different items stocked was least for Model II B.

An examination of Tables 5 and 7 indicates that for items not stocked, Models I and II A performed about the same; Model II B performed less well than the other models because of its reduced range of items stocked. For stocked items, however, Model I performed better than the other models; the performance of Models II A and II B was very similar. Thus, on the basis of the shortage measures alone, Model I was ranked higher than Model II A because it had fewer shortages for stocked items. Model II A was ranked higher than Model II B because it had fewer shortages for nonstocked items.

TABLE 7. Items With No Previous Usage History [a]

Items	Shortages: All items	
	Range [b]	Depth [c]
Not Stocked:		
Model I	1.0 (1.2)	1.7 (2.1)
Model II A	0.9 (1.4)	1.5 (2.0)
Model II B	6.0 (6.4)	10.1 (10.0)
Stocked:		
Model I	3.6 (3.5)	33.8 (53.6)
Model II A	6.1 (4.3)	48.4 (58.8)
Model II B	5.3 (4.0)	44.6 (57.7)

[a] Averages for 35 patrols. Standard deviation in parentheses.
[b] Number of different repair parts with shortages.
[c] Number of units short over all repair parts.

One should note that the difference in performance between Models I and II A was small. Model I had 3 to 4 fewer items with a shortage per patrol; given a shortage, the number of units short per item short was at most one less for Model I. On the other hand, the difference in investment cost between the two models was substantial. Model I was approximately 2 to 3 times as expensive as Model II A. The difference in performance between Models II A and II B, was about the same as that between Models I and II A. In terms of investment cost, however, Model II B was somewhat less expensive than Model II A.

The finding of small differences in performance between models is reinforced by an examination of shortage counts for those repair parts which were highly essential.* Shortage counts for this class of items are found in Table 8. As may be seen, for these items, with the exception of the *depth shortage* measure for stocked items with no previous usage history, all models performed about the same.

TABLE 8. Shortages for Highly Essential Items

Items	Highly essential items [a]			
	With previous usage history		With no previous usage history	
	Range (1)	Depth (2)	Range (3)	Depth (4)
Not stocked:				
Model I	0	0	0.1	0.2
	(0)	(0)	(0.2)	(0.7)
Model II A	0	0	0	0
	(0)	(0)	(0)	(0)
Model II B	0	0	0	0
	(0)	(0)	(0)	(0)
Stocked:				
Model I	2.2	19.1	0.1	1.7
	(3.4)	(27.4)	(0.2)	(7.8)
Model II A	2.4	23.3	0.4	5.1
	(3.7)	(33.9)	(0.6)	(11.2)
Model II B	2.3	23.2	0.6	5.5
	(3.6)	(33.9)	(1.2)	(11.8)

[a] Averages for 21 patrols in Cols. 1 and 2. Averages for 35 patrols in C[illegible]

*A discussion of military essentiality coding of repair items is found in [illegible]

Based on the findings of this section, we conclude that relative to the substantial difference in investment cost between Model I and Model II A, the difference in performance between these two models was small. Considering cost as well as performance, Model II A was judged superior to Model I. Because of the fewer shortage counts for Model II A vis-a-vis Model II B and the similarity of costs between them, Model II A in which items were distinguished by nomenclature class was judged superior to Model II B where all items were lumped into a single class.

4. SUMMARY

In this paper a model is presented which focuses directly on the difficult problem of predicting demands for items with extremely low usage rates, which form the bulk of repair parts in military systems. In the model, repair part demands are assumed to be Poisson distributed while their means are assumed to be gamma distributed. A basic notion underlying the model is the pooling of usage data for items that have shown some movement for the purpose of estimating usage rates for those items which have shown no movement.

At the outset, repair parts were partitioned into different classes. An assessment of goodness-of-fit was performed for 54 different classes of items to determine whether the unconditional distribution of demands was indeed negative binomial distributed as postulated by the model. Given the vagaries of the data, e.g., disproportionately large numbers of even demands and large outliers due probably to mispunched data and stockpiling of material, the model fit the data quite well. Although the partitioning of repair parts was not essential to the model, it was assumed that such partioning would yield improved estimates of usage rates. The goodness-of-fit computation and other tests conducted in an inventory context suggest that this indeed was the case.

A unique feature of the model is that in addition to providing positive usage estimates for repair parts with previous usage history, regardless of whether or not a particular part was observed to move, the model also makes possible the estimation of usage rates for new items for which no previous usage history is available. In an inventory context under stringent test conditions, the model performed equally well under both contexts, when compared with the current procedure for estimating usage rates. Mean shortage counts for the model were slightly higher over all items and about equal for highly essential items as mean shortage counts for the current procedure. On the other hand, differences in cost were marked with the current procedure costing two to three times as much as the proposed model. As indicated by this study, the notion of pooling usage data, and from such data extrapolating usage rates for installed items with zero usage or for items being newly introduced into a system, is a useful one.

ACKNOWLEDGMENT

The authors wish to thank William Hise and Talbot Walls, Jr., for their programming assistance.

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15

SUPPLY SUPPORT - PART 1

The Allowance Parts List

By Mr. R. G. Hakemian

Material Planning and Programming Division,
Naval Sea Systems Command

(Editor's Note: The following 4 articles on Supply Support originally appeared in the "NAVSHIPS TECHNICAL NEWS" *and are reprinted with the kind permission of the Editor.*)

In the middle of a Fleet operation, a shipboard maintenance technician has quickly and accurately diagnosed a problem. He knows positively which part of an inoperative piece of equipment is causing the problem. He has every reason to feel satisfied. *"Right?"* Even the greenest shipboard technician will soon answer, *"Not necessarily!"* Of all the frustrations he can encounter on the job, probably no one situation is as demoralizing as knowing which part to replace but not being able to identify it or obtain it from the Supply Department.

There are any number of valid reasons for such an unhappy ending. Unfortunately, there are also a great number of invalid reasons that might have caused it. We feel it is important that Fleet technicians understand how supply support for their equipment is developed, what technical aspects are considered and what financial and personnel constraints are imposed on the process. Most importantly, we want the technician to know how he, as an individual, can help close the inevitable loopholes. We also want him to know that some things are beyond his, or in some cases the Navy's ability to control. If you feel the same way, read on. (Even if you don't, we'd like you to.)

In June 1972, the *NavShips Technical News* (now the *NavSea Journal*) contained a feature article devoted to the Coordinated Shipboard Allowance List (COSAL) and its driving force, the Fleet Logistic Support Improvement Program (FLSIP). That informative article appropriately portrayed the COSAL process from a Supply Department point of view. The article concentrated on how COSALs are constructed, the use of 3-M (Maintenance and Material Management) data to establish demand rates used for allowance computation, as well as presenting the computational logic itself. It also explained that the COSAL development process involved a series of technical and maintenance decisions. Those decisions, along with logistic support doctrine and business decisions, combined in the computation process eventually determine the mix of repair parts allowed onboard ship.

Beginning with this article, we will try to further your understanding of the technical side of allowance and supply support. We will concentrate on the importance of the technical and maintenance decisions that largely drive the onboard supply support process. Subsequent articles will address configuration, the COSAL itself, and allowance change requests. Although many of the methods are employed Navywide, the article will specifically address support methods and procedures for NAVSEA equipment and components exclusive of nuclear propulsion and FBM material.

The Allowance Parts List (APL) -- Your Maintenance Plan

APLs make up the technical portion of the COSAL. To date approximately 300,000 APLs have been published; however, only those APLs for equipment contained in a particular ship's configuration record will be included in that ship's COSAL. The importance of an accurate configuration file deserves separate attention and will be discussed in another month.

The APL is of particular interest to the technician. The APL is not just a piece of paper to identify stock numbers; it is usually the only document onboard that reflects in detail the maintenance philosophy of the office having technical cognizance of the equipment or component. That policy is implemented through a series of maintenance and technical decisions when a component plan is displayed in the form of technical codes in the columns illustrated in Figure 1. The codes will appear opposite each maintenance significant part listed. In addition, most APLs contain a summary of the component's technical characteristics.

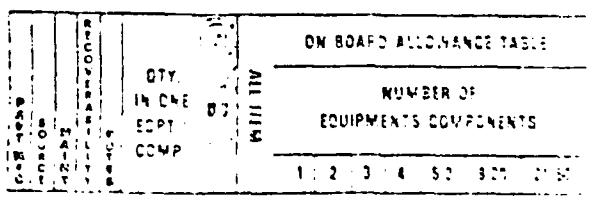


Figure 1

The Technical Decision Process

Let's look for a moment at who makes the technical decisions and how they become technical codes. Later on, we'll discuss the codes individually.

The Chief of Naval Material requires hardware systems commands (for example, NAVSEA for most shipboard components) to ensure that technical and maintenance decisions, necessary for the development of supply support, are made. He expects the APL to accurately reflect the maintenance policy for the systems command or office having technical responsibility for a component. He therefore holds the systems commands responsible for the technical integrity of allowance lists. Examples of the technical decisions required for a component and each maintenance significant part are:

- Should the entire component be supported by the Navy Supply System?
- Should an item be stocked by the Navy Supply System?
- Should repair be limited to replacement of the whole component or replacement of defective items within the component or should it be repaired at all?
- What type ships will be authorized to remove and replace an item? Repair an item? Dispose of it?
- Will repair be accomplished by a tender or depot or, perhaps, a contractor?
- What is the minimum replacement unit (i.e., if one fails how many should be replaced)?
- *What is the essentiality of an item to the function* of the component?
- Is there an overriding mission, safety or planned maintenance requirement to carry a spare part onboard?
- If it is a new item and 3-M usage data is not available for similar items operating under similar circumstances, what is the expected failure rate?

Decisions are made and technical codes are assigned, for the most part, in one of three ways:

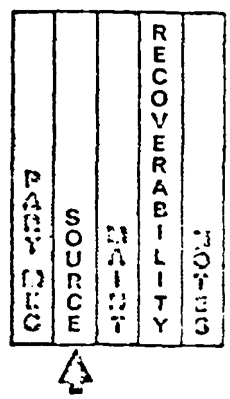
- As a result of a formal Maintenance Engineering Analysis (MEA) which is normally performed by the equipment manufacturer and approved by the Navy. It is appropriate to mention that a newer technique, entitled the Logistic Support Analysis (LSA), serves the same end and will eventually become the dominant engineering-analysis tool used by the Navy to develop logistic support.

  An MEA is expensive and therefore generally restricted to complex shipboard system acquisitions (such as, sonar systems, large propulsion units, etc.).

- During a provisioning technical documentation review conference, by Navy maintenance engineers. Engineering responsibility for NAVSEA equipment is assigned to Commander, Naval Ship Engineering Center (NAVSEC). This function is usually performed by the NAVSEC Mechanicsburg Division. This method is usually employed for electronic equipment and complex Hull, Mechanical and Electrical (HME) equipment.

- By the Lead APL (LAPL) method. Under this method, a NAVSECMECHDIV engineer makes the technical and maintenance decisions for a category of components (e.g. pumps, valves, drinking fountains), on a one-time basis. He then documents the technical codes on the LAPL. For example, all bearings in a component, let's say a motor, would be assigned one set of codes, all brushes another set, and the armature yet another set. The LAPL then becomes a blueprint for preparing an actual APL for a specific make and model motor. The LAPL method is employed for most HM&E equipment. The LAPL is also used as a guide for shipbuilders to prepare provisioning technical documentation and determine repair part procurement requirements.

The most effective technical-decision method is the MEA. As noted, it is also the most expensive. The next most effective way, and somewhat less expensive, is the provisioning conference method, but when one considers that there are complex shipboard equipment items that contain over 70,000 maintenance significant parts, it becomes apparent that a point of diminishing returns is reached if the complete decision process is applied to every resistor, filter, gasket, etc. As a result, preliminary technical decisions are generated mechanically and stand unless specifically changed by the engineer.



THE SOURCE CODE

Figure 2

The most efficient method, in terms of decisions rendered per engineering manhour, is the LAPL method. The principal disadvantage is the lack of an engineering review during specific technical coding assignments and the possibility that a "state of the art" advance will not be recognized by technicians selecting and using a LAPL when assigning technical codes for a specific [illegible]

Considered collectively, these technical codes now reflect the Navy's maintenance plan for the equipment or component supported by the APL. When the technical code assignments are complete, and other data elements reflecting characteristics and supply decisions have been entered in the Ships Parts Control Center (SPCC computer records), an APL can be produced.

APL Display

Assuming your interest hasn't been completely dampened by the Headquarters-based "technical decision process" discussion, we'll move on to the portion that directly impacts the Fleet, the technical codes.

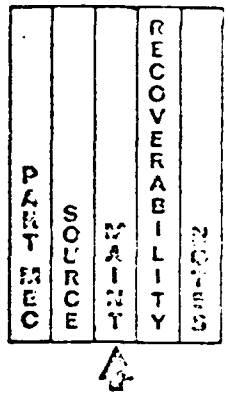
The source code might reflect the decision to stock an item in the Supply System. It might also indicate another means of acquiring the item. Quite simply, if the first position of the 2 position codes begins with a "P," it will be stocked for Navy support and will be identified with a National Stock Number (NSN). If any other code is assigned to the first position, the item will not be stocked, initially at least. The latter decision may be made for various reasons; i.e., the item is not expected to fail or it is more economical to manufacture in the shipboard machine shop.

The second position is not of prime concern aboard ship. It primarily guides inventory management decisions. If, for example, during the technical review of an item it is determined that little demand is expected because only a catastrophic failure of an item would require its replacement, a decision may be reached to procure and maintain one in the supply system due to the high criticality of the item.

Examples of common source codes are:

- PA - Item procured and stocked for anticipated or known usage.
- PB - Item procured and stocked for insurance purposes, because essentiality dictates that a minimum quantity be available in the supply system.
- XA - Item is not procured or stocked because requirements for the item will require the replacement of the next higher assembly.
- MO - Item to be manufactured or fabricated at the organizational level

The Maintenance codes reflect decisions such as what type ships are authorized to remove or replace a component or part and who (if anyone) is authorized to repair it. Specifically, the first position identifies the lowest maintenance level authorized to remove and replace the item. If organizational, i.e., shipboard, replacement is indicated, the first position further indicates the lowest shipboard maintenance



THE MAINTENANCE CODES

Figure 3

capability level by ship type categories. Figure 4 contains breakdown of the common maintenance capability level coding.

The second position of the maintenance code answers the question "who is authorized to repair an item." It identifies "who" by displaying the code of the lowest maintenance capability level authorized to do complete repair of the item regardless of what may go wrong with it.

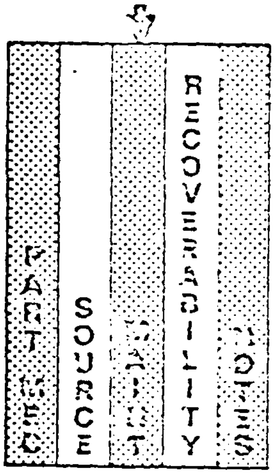
Let's look at an example. An ET, EM, FT, etc., maintains equipment containing printed circuit boards. Looking at the APL, we will find information relative to the circuit board and parts mounted on that board. As an example, Figure 5 portrays how the circuit board itself and 4 parts mounted on the board would be displayed. It is important to emphasize that the example could be a motor and include the armature, brushes, bearing, etc., used in the motor.

MAINTENANCE CAPABILITY LEVEL CODES

- ORGANIZATIONAL
  - 2 - MINESWEEPER YARD CRAFT, PATROL GUNBOAT
  - 3 - SUBMARINE
  - 4 - AUXILIARY - AMPHIBIOUS SHIPS (APA AKA AO etc)
  - 5 - MINOR COMBATATANT (DESTROYER FRIGATE ESCORT
  - 6 - MAJOR COMBATANT (CRUISER CARRIER)
- INTERMEDIATE
  - F - TENDER, REPAIR SHIP etc.
  - H - SHOREBASED INTERMEDIATE
- DEPOT
  - D - SHIPYARD
- OTHER
  - Z - NOT REPLACEABLE AT ANY LEVEL (FIRST POSITION) OR NOT REPAIRABLE AT ANY LEVEL (SECOND POSITION)

Figure 4

THE MAINTENANCE CODE



Circuit Card Assy	1	PA	2F	F	1
Capacitor, Fxd	1	PA	FZ	Z	
Transistor	1	PA	2Z	Z	
Connector	1	PA	4Z	Z	
Bracket	1	MO	2Z	Z	

Figure 5

Looking at the 2 position maintenance code and referring back to Figure 4, we find under the first position that maintenance personnel on a minesweeper are authorized to remove and replace the circuit board. Being a "level 2" ship, its ET can remove and replace the transistor and the bracket, but not the capacitor and the connector. The same technician assigned to an auxiliary ship, "level 4," is also authorized to remove and replace the connector. He still is not authorized to replace the capacitor, as the "F" code indicates that only a "tender level" ship can replace it.

Under the second position we find that, with the exception of the circuit board itself, all of the items are coded "not repairable," i.e., when the transistor fails, replace it and throw the bad one away. However, the circuit board carries an "F." This means that only a Tender or higher (i.e., a depot) maintenance level is authorized to perform complete repair. This is consistent with the first position coding in that only the tender or higher could replace the capacitor, but various ship types could effect some repair.

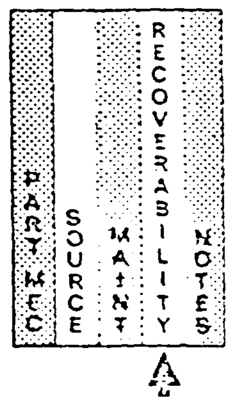
For drill, apply a little technical logic to the example and see for yourself how the technical coding tracked the decisions of the maintenance engineer. The conclusions he reached in making his desicions were:

- The circuit card is simple to remove and replace.
- Troubleshooting by use of circuit card interchange is taught at the appropriate "systems school."
- All transistors are plug-in type. Sockets are an integral part of the board.
- The connector may be replaced with a 25-watt soldering iron without damage to the board.
- The bracket is made of common aluminum and is mounted with common hardware.
- Soldering techniques are taught in the basic "school" for the maintenance rating.
- All other parts on the board are protected by a hard coating. Replacement would require special tools, provided to tenders but not to onboard organizational-level technicians.
- Level of Repair analysis indicates repair of the board should be accomplished whenever it fails.

Before we leave the example, notice that the bracket is not available from the Supply System. The source code tells the technician to fabricate a replacement bracket.

The recoverability code identifies the lowest maintenance capability level authorized to condemn an item. The level, found in this single position code will usually match the second position of the maintenance code, which would indicate for a non-repairable that if you can remove and install it, you can dispose of it.

Therefore, don't assume you can throw a specific item away just because you are authorized to perform some repair on an assembly.



THE RECOVERABILITY CODE

Figure 6

One final point with regard to the 2 position maintenance code and the last position recoverability code. Always remember that the first position indicates the lowest level authorized to remove and replace an item. The second position and the last position recoverability codes indicate the level authorized to accomplish complete repair or condemn an item.

A complete breakdown of all SM&R (source maintenance and recoverability) codes is contained in NAVSUPINST 4423.14. The maintenance capability for specific hull designations (i.e., DLG, AE, SSN, etc.) are contained in NAVSHIPINST 4441.3[illegible] Change 1.

Codes listed under the captions "NOTES" and "PART MEC" also convey information to the technician. NOTES, or more correctly, the allowance note code identifies special supply support consideration; for example, NOTE CODE "1" indicates in Figure 5 that an item is designated as an OSI (operating space item). It should be carried in the same relative location as the component instead of in the storeroom. A complete breakdown of allowance note codes is contained in the COSAL introduction.

"PART MEC," short for "military essentiality code, part to component," indicates, as the name would imply, the importance of an item to the component. On an APL, it specifically identifies whether a specific item is critical to the operation of the equipment or component supported by the APL. While seemingly insignificant, the code controls entry to the COSAL insurance item computation. If an item is coded "3" (i.e., non-essential), it will not be authorized as an onboard spare unless prior usage indicates that the ship will require at least one each quarter. The importance of MEC will be covered fully in a later article.

Three other technical codes that are not displayed on an APL play important roles in computing onboard allowances. That role will be discussed in detail during the *third article of this series*. Briefly, they are:

- AOR (allowance override requirement). This code answers the question, "Is there an overriding reason to carry this item onboard?" The most common reason is that the part is a direct determinant of a primary mission of the ship.
- MRU (minimum replacement unit). This code indicates the minimum quantity normally replaced during a maintenance action.
- TRF (technical replacement factor). This code is assigned for new items when 3M usage data is not available for similar items operating under similar conditions.

Electronics APLs

The Navy Ships Parts Control Center (SPCC) prepares APLs with an additional technical feature. Section B of the APLs is structured in circuit symbol number sequence. The rationale behind this approach is that electronic technicians are most familiar with circuit symbol orientation. Most technical training and most technical manuals utilize the same orientation. If a technician knows that "CR 7" is bad, his APL will tell him that the CR 7 he requires is a 1N914 semiconductor. This feature additionally provides specific SM&R coding for each application of an item. It also lists all applications of maintenance significant items, whether or not they are supported in the supply system.

HM&E APLs

HM&E APLs have not ignored the technician either. In the first portion of each APL, SPCC has documented certain characteristics data. The data is intended to provide the shipboard technicians with pertinent technical information. It is also intended to assist personnel in positive identification of support requirements for a particular component.

What's on the Drawing Board?

As stated earlier, CHNAVMAT holds NAVSEA responsible for the technical integrity of allowance lists for our equipment. It is our objective that those allowance lists be improved. As a minimum we feel that allowance lists for all complex equipment should be oriented to the training methods and technical manuals or drawings available to the technician: for example, if a technician responsible for maintaining laundry equipment is taught to diagnose using disassembly exploded views, then his allowance list should be structured accordingly. Similarly, if an internal communications technician must perform corrective maintenance using ship's electrical circuit drawings, then his APL should be oriented to the plan, sheet, and item or piece number.

Another primary objective to improve the technical integrity of our APLs is to develop the capability for all APLs to identify maintenance significant items, whether or not the item is available from the supply system.

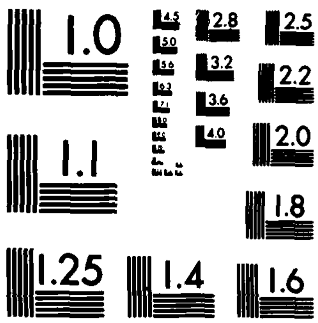
How Can the Fleet Help?

Much earlier we described "the technical decision process" used to develop APLs. You know that many of the technical codes are assigned by machine or on the basis of one-time decisions. These codes should be correct in most situations. In some, however, they may not be correct. In other cases, the original technical decision that drives the technical code assignment might be wrong (we're human too!). The simple fact is, that the Navy can't afford an engineering analysis of every part in every application on every ship. We attempt to emphasize the areas where we expect the biggest return.

Therefore, if you believe the technical code for an individual item, or the over-all maintenance policy reflected by all of the codes on an APL are wrong, do something about it. Don't just live with it or try to get around it.

You can best help yourself and your sister ships obtain proper supply support by jotting down your

AD-A099 777 SURVEY AND ASSESSMENT OF MODELS OR DECISION RULES 6/10
DETERMINING SPARE PARTS..(U) AUTOMATION INDUSTRIES INC
SILVER SPRING MD VITRO LABS DIV R I POWELL ET AL.
UNCLASSIFIED 07 SEP 79 TR-03133.100-1-APP-A F/G 15/5 NL



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

... technical problem and sending it and your rationale to:

OFFICER IN CHARGE
Naval Ship Engineering Center
Mechanicsburg Division
Mechanicsburg, PA 17055

Tell the NAVSECMECHDIV engineer that you really can replace that bearing and do it routinely on other components. Tell him that the O-rings in the pump you're supposed to rebuild are not even listed on the APL. Tell him that the power supply assembly inside your switchboard isn't on the APL, but the ringer assembly is and so is the relay assembly. Tell him that the 500 light bulbs inside the indicator lamps on your propulsion control system panel can be replaced individually, but the APL says to replace the whole lamp. Tell him as much as you can and be sure to give him a point of reference; either the APL, if addressing the technical codes, or the technical manual if parts do not appear on the APL.

Remember, you will do little to help yourself by making a general statement that supply support for the AN/UYA-17 is bad. If the problem is a poor APL, then we can best solve the problem by having the technical side of the Fleet communicate directly with the technical side of supply support.

The moral of this story is: We look at you (the shipboard technician) as a member of the technical supply support team--"the vital feedback link."

In the next article we'll look at configuration, the baseline for supply support. One of the objectives of that article will be to let you know why in some instances an APL does not exist and may never exist.

SUPPLY SUPPORT - PART 2

The Configuration Baseline

By Mr. R. G. Hakemian
Material Management Division
Naval Sea Systems Command

Part 1 of this series of 4 articles pointed out the importance of the Allowance Parts List (APL) to the shipboard technician. It stressed the point that the APL is not just a supply document, but is actually an onboard maintenance plan. It described the technical decision process used in developing APLs as well as the specific coding techniques used to display those decisions on an APL. It also pointed out some of the fallacies inherent in the process. Finally, it told you, the shipboard technician, how you can help yourself and your sister ships obtain proper supply support if you spot a problem with an APL.

Something must happen before the APL for your equipment becomes part of your ship's Coordinated Shipboard Allowance List (COSAL). If the best maintenance engineer in the world makes the APL Technical decisions for an equipment item, it is not going to result in your having any of the repair parts you need unless that specific APL is in your COSAL. A well documented configuration baseline is the bridge from a quality APL to quality supply support in your COSAL.

The Configuration File

The key to the COSAL door is the mechanized configuration file at the Ships Parts Control Center (SPCC) in Mechanicsburg. Each ship has its individual record in that file. Now a computer, especially one located in the middle of Pennsylvania, isn't going to know what equipment is installed onboard a ship unless someone on the waterfront tells it. Reduced to its simplest elements, a configuration baseline answers the questions:

- What is aboard?
- How many of each are there?
- What is the field change status of each?

The configuration must be established and reported well before a ship receives its first COSAL during new construction and that baseline must be maintained as changes occur during overhauls and shipyard availabilities. Let's examine the methods used for NAVSEA (less nuclear propulsion) equipment.

New Construction

While the ship is being designed, technical documentation flows from the shipbuilder to the Naval

Supervisor of the shipbuilding effort. The configuration is established from that documentation in the following manner:

Within the allowance division of the Supervisor's office, a technical specialist reviews the documentation and identifies specific components and equipment. He then prepares a mechanized transmittal that contains the data elements necessary to load the configuration file. The transmittal forms are then sent to SPCC and the file is loaded.

Once the file is loaded, a COSAL may be prepared. The exact configuration that the COSAL is based upon is reflected in its index. The COSAL index is printed in two sequences: Section A lists all components in the configuration file in "nomenclature" sequence while Section B lists the same components in "service application" sequence. Except as noted later in this article, if it isn't listed in the index, then you will not find repair parts for it onboard.

The Allowance Support Codes

The COSAL index will tell you whether an APL exists for a component, and in some cases whether one will ever exist. The key to the latter bit of information is the last 2 positions of the "Allowance Support Codes." The most common codes, found in the last 2 positions, are "AA." Simply stated, the codes respectively mean:

A = Full onboard support is to be provided.

A = An APL is included in Part II and support is included in the SNSL (Stock Number Sequence List), Part II of the COSAL.

While the "AA" combination is the most common of those appearing in the last 2 positions, it is important always to check those codes when using the COSAL. Almost any combination, other then "AA" carries a special message to the technician and storekeeper. A complete breakdown of the codes is contained in the HM&E (Hull, Mechanical and Electrical) COSAL Introduction and in ESO INST 4441.17E, an Allowance Program Guide provided with each COSAL. To illustrate, consider the following examples that might appear in the COSAL Index:

Nomenclature	Allowance Supt Code
CCVJ-MK7 radar set	JEP <u>AU</u>
CGG-H23-FFN-1100N, handie talkie transceiver	EEP <u>FD</u>
LS-474/U, loudspeaker	JEP <u>EE</u>

In the first example, the message contained in codes "AU" is that the MK-7 radar set is fully supported in the COSAL but, due to the variable configurations available, an APL is not provided for the whole radar. However, an APL is provided for each component of the radar set. If you are trying to identify a transmitting tube, the transmitter unit listing in the index will identify the APL for that unit.

The message relative to the "walkie talkie" is quite different. "FD" means that the Naval Material Command has determined that onboard support will not be provided, an APL does not exist, and there are no plans to make one. If the unit fails, parts may be ordered from the supply system by manufacturer's reference number or they may be procured locally.

There can be many reasons for "FD" support determinations. The most common is that it is not economically feasible to provide full Navy Supply System support because of non-essentiality, low number of units in the Fleet, or availability of parts on the commercial market.

In the last example, "EE" tells you that the whole unit is viewed as expendable. You will not find an APL and onboard support is not provided.

Allowance Appendix Pages

That a ship's COSAL is never complete is a fact of life. Last minute changes during new construction, replaced components during repair and overhaul availabilities, and just plain old errors all contribute to that fact. To maintain support between COSALs, the allowance division of the Naval Shipyard or Naval Supervisor's office prepares allowance appendix pages for components changed during availabilities. These pages augment the COSAL. Either the pages are combined into a package that includes a COSAL-type index or the Ship's COSAL index itself is annotated to reflect the added components. Concurrently, SPCC updates its configuration file to be ready for the next COSAL.

Ship's Responsibility

The ship is responsible for reporting any discrepancies found in the COSAL index. Whether the discrepancy is caused by an existing error or because of a change in components, the change must be reported if the integrity of the configuration baseline is to be maintained. HM&E (hull, mechanical and electrical) equipment changes and corrections are reported to SPCC. Detailed instructions are contained in the COSAL Introduction. Electronic equipment changes and corrections are reported to the SECAS Validation Field Office, via the Type Commander. Instructions are contained in NAVSHIPS Publication 0967-455-6040, the SECAS (Shipboard Equipment Configuration Accounting System) Program Manual, Vol. 4.

Validation

The quality-assurance aspect of the configuration baseline system is validation. Validation is the process of taking a physical inventory of equipment onboard and verifying that the configuration record represents an accurate baseline of the equipment.

During new construction, the Naval Supervisor of Shipbuilding is responsible for validating all ordnance and electronic equipment, as well as all major machinery components.

After new construction, a ship normally receives a new COSAL incident to an overhaul. Prior to that overhaul, SECAS sends trained specialists onboard to validate the shipboard baseline. Initially, SECAS validated only the electronic equipment onboard. Currently, however, the SECAS validation is being expanded to include HM&E.

In the meantime, the validation of HM&E rests with the ship. Under present procedures, SPCC will provide HM&E validation aids to the ship about 10 months prior to the overhaul. The validation aids are based upon the baseline information in the SPCC configuration file. The quality of the new COSAL will be directly proportional to the quality of the validation effort and the accuracy of the updated information fed back on the validation aids.

During Overhaul

During an overhaul, a technician may find himself assigned to the Supply Operations Assistance Program "T Division." On the surface you may feel that there are more important things to be done than looking at parts and shuffling EAM cards. However, the supply support of your ship can be enhanced considerably by your performance. Your technical expertise is needed.

The configuration reflected by your new COSAL will be altered whenever a component is replaced with a different component resulting from overhaul open-and-inspect repair work. When the T. Division receives an allowance appendix package covering these changes, you should examine closely those documented in your area of shipboard responsibility. If you suspect any errors or voids in the configuration changes, you can help yourself by getting onboard and validating the component in question. If an error exists, call it to the attention of the allowance preparation activity. You will not only receive correct support for post overhaul deployments, but will ensure that the next COSAL reflects the correct components.

What's On The Drawing Board?

As mentioned above, pre-overhaul validations have already been taken over by trained SECAS electronic equipment specialists. Soon, already busy crews will be relieved of much of this burdensome chore as SECAS expands into the machinery spaces.

On the new construction front, the FOMIS (Fitting Out Management Information System) will provide the ship's crew with a wealth of information about their new ship. Now in its pilot application, FOMIS is a NAVSEA system for monitoring and displaying the logistic support progress and status of all shipboard equipment at the component level.

The FOMIS concept is based on establishing an original mechanized record for each component which will ultimately constitute the ship's configuration. The record is initiated from design, material requirement, and purchase documents. It is updated with more specific information as it becomes available during the construction process.

Specifically, FOMIS is designed to improve the accuracy of the ship COSAL by providing early and accurate configuration definition, improving allowance support available at the end of construction, providing a centralized bank of data for reporting status information to activities responsible for managing and supporting the construction and fitting-out effort, and providing an accurate and complete equipment configuration baseline for each ship as delivered. The configuration data is used to load the Weapon System File at SPCC which, in turn, controls the configuration input to the COSAL process. FOMIS output products of interest to shipboard personnel include:

- Technical manual listings in equipment nomenclature and publication number sequences.
- APL to EIC (Equipment Identification Code) relationships.
- Summary listing of Allowance Appendix Pages crossed to APL numbers.
- Listing of non-APL worthy items, to supplement the COSAL Index.
- Listings of Technical Manual shortages in two sequences.

So far we've discussed the inputs in our shipboard supply support story. Hopefully, you've been able to understand the role of the technical command and the shipboard technician in the process. In Part III, we'll look at the COSAL computation itself and try to help you understand why that bearing you need so desperately today wasn't allowed in your storeroom when your allowance was established. We'll also tell you what you can do about it if it was computed on "bum dope."

SUPPLY SUPPORT - PART 3

The Coordinated Shipboard Allowance List Computation

By Mr. R. G. Hekemian
Material Planning and Programming Division
Naval Sea Systems Command

Part I of this series of 4 articles described a parts availability situation faced all too frequently by shipboard maintenance technicians. In that situation, a problem had been quickly and accurately diagnosed, but the failed part was not available from the Supply Department. Chances are, it was not even allowed as an onboard repair part by the ship's COSAL.

The article explained that there could be a number of valid reasons why the part was not allowed and mentioned that there were also quite a few not-so-valid reasons that could have been responsible. In describing the technical decision process used in the development of an APL (Allowance Parts List), Part I also pointed out some of the fallacies in the process, how they might have caused the "not allowed" situation, and what the shipboard technician could do if he suspected that an incorrect technical decision was at fault.

Part II stressed the importance of a well documented configuration baseline to quality onboard support in your COSAL.

As illustrated in Figure 7, both Part I and Part II addressed inputs to the allowance determination process. In this article we'll look at the COSAL computation model. We'll also look at some of the basic constraints that affect the computation so that you can understand some of the valid reasons why that part you need so desperately may not have been included in your repair parts allowance.

If your Supply Officer was allowed a crystal ball, I'm sure that he would look ahead and make sure that he could provide every part that was going to be needed during your next deployment. We would be happy to provide each one, and we'd probably also agree that the CNO would like to give us enough money to provide every part that you might need to support your equipment. The two problems with this theory are obvious. First, the Supply Officer doesn't have a crystal ball. Second, analysis of 3-M data shows that the demand for repair parts aboard ships is highly random and, therefore, the Navy will never have enough money to provide all of the parts that are destined to fail someday. In fact, the Navy has been criticized for spending too much money in this area.

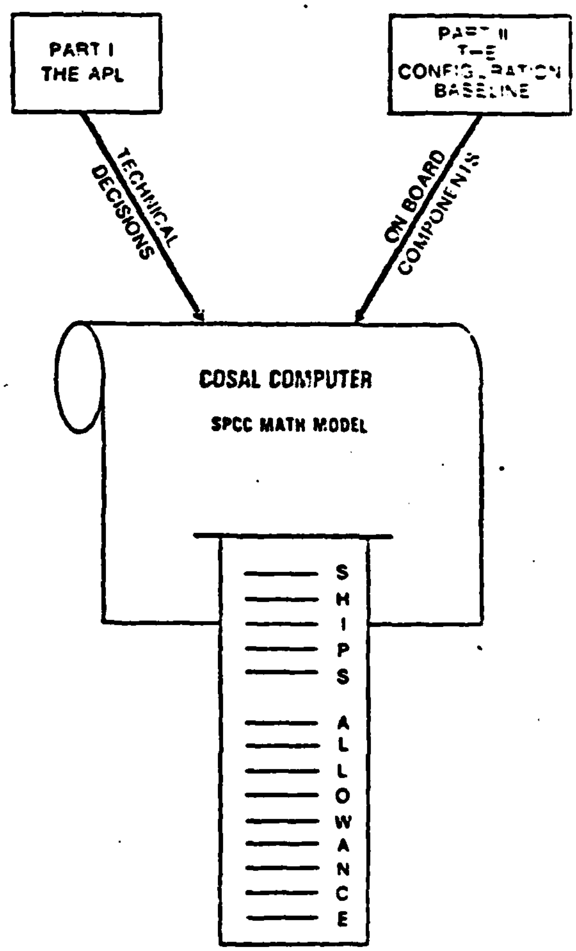


Figure 7

To make the shipboard allowance money go around or, more properly stated, to best use the resources available to the Navy for this purpose, CNO has specified specific logistic support doctrines governing onboard repair parts. Although we might view this doctrine as a constraint, the rules are actually a third input to the COSAL process. In fact, they establish the criteria that governs the make-up of the Ships Parts Control Center COSAL math model.

An overriding rule is that the ship must have the capability to install a part before it can be considered as a candidate for its allowance. As you might remember from Part I, in determining this capability, the availability of trained personnel, tools, and maintenance data onboard the ship was a prime consideration. In addition, the capability to install a particular part may have been denied a ship because analysis had shown that it was more economical to replace the whole component when failure occurred.

Before we pursue the more specific rules, let's examine the objectives behind them. While the basic CNO objective may be to make the repair part dollars stretch as far as possible, the stated objectives are those appearing in Figure 8.

OBJECTIVES CNO RULES FOR SHIPBOARD ALLOWANCES

- OBJECTIVES
  - GROSS EFFECTIVENESS - 65%
  - COSAL EFFECTIVENESS - 85 %
  - DEMAND BASED ITEM PROTECTION - 90 %
- REPAIR PART CATEGORIES
  - DEMAND BASED - 1 IN 90 DAYS
  - INSURANCE - 1 IN 4YRS.
  - ALLOWANCE OVERRIDES - MINIMAL
  - SIM -HEAVY DEMAND EXPERIENCE
- MUST BE WITHIN SHIPS MAINTENANCE CAPABILITY

Figure 8

Gross Effectiveness -- 65%

The message here is that the technical decision process, constrained by rules we'll look at in a minute, will result in a COSAL allowance that will meet at least 65% of all repair part demands placed upon the Supply Department

COSAL Effectiveness -- 85%

By the objective, the depth (i.e., quantity of each item) allowed by the COSAL will result in issues by the Supply Department 85% of the time that those items are demanded. Obviously, the response of the Supply System, when you requisition replacements for expended allowance items, plays a big role in whether you can meet either of these objectives during a deployment.

Special Rules

The objectives clearly establish that the CNO recognizes that he cannot provide every item that might fail. While leaving the technical decision process up to the Material Hardware Commands (e.g., NAVSEA), specific rules are stated for various categories of items.

Demand-Based Items

We noted earlier that demand for repair parts is highly random. Therefore, of the thousands of repair parts which a given ship has the capability to install, only a limited number will be fairly regularly used. CNO has categorized those parts as "demand based" items if they are used aboard ship at least once during a 90-day period.

The rule for such items states that allowance lists must provide a 90% probability of filling the total demands for these items over an entire operating period or, conversely, that there should be only a 10% risk of the item being out of stock. CNO also requires that these computations be based on combat consumption rates, wherever such rates can be ascertained.

Insurance Items

All installable repair parts which are predicted to be used in maintenance less often than once in 90 days are categorized as insurance items. The rules state that only those insurance items with a .25 or greater expectation of usage aboard a ship in a one-year period will be stocked. To state this another way, only those insurance items which have an expected usage of at least one in 4 years will be stocked. Until about a year ago, this criteria was .15 per annum or one in 6-2/3 years. As the Navy was allowed fewer repair parts dollars, the insurance criteria was tightened.

As a further restriction, these insurance items may be considered only as allowance candidates if they are essential to the support of equipment that is considered vital to the operation and mission of the ship.

Allowance Overrides

The rules also allow a few items not falling in the above categories to be forced onboard by allowance overrides when special circumstances exist. These are restricted to items:

... or welfare
... planned maintenance

... of the primary mis-

... controlled by the Chief
... thresholds have been
... ionate share of re-
... ated in support of a
... few highly critical
... override method.

... Management)

... CNO to carry items in
... those items are experi-
... program, known as the
... (SIM) program, has
... of years. In effect the
... adjustment of COSALs
... ring. This usage is con-
... levels when subsequent

... that the CNO objectives,
... been attained in most in-
... shown that it would be
... jectives within reasonable
... authorized exceptions to the
... tably for onboard support
... for total FBM submarine
... the FBM onboard support
... to the investment under
... have just discussed, but
... above 90% has been
... marines.

... Mix," or the
... ,000.00) Question

... payoff, the most "bang
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... It is in this fertile area
... ovement lies. The area
... continues into the tech-
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... look at how the Naval
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... mathematical logic and
... ermine final onboard
... in your COSAL.
..., the SPCC component

COSAL COMPUTATION LOGIC

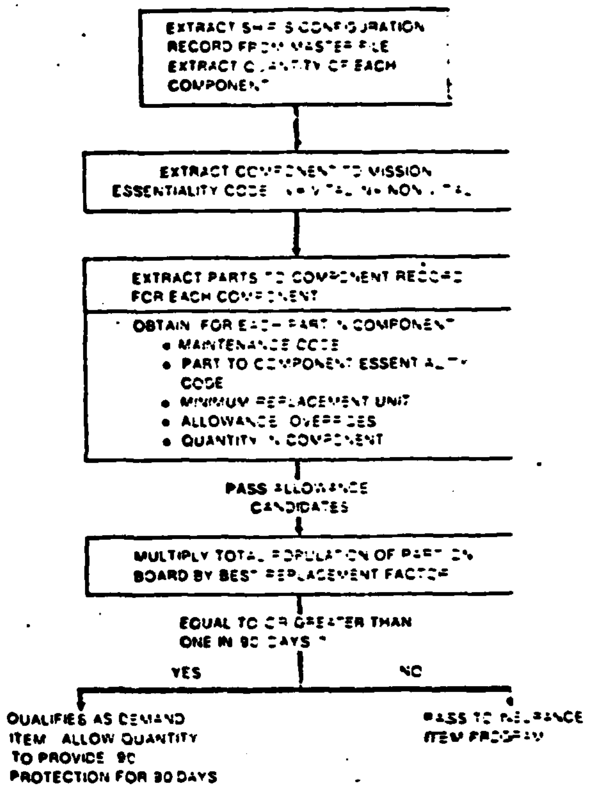


Figure 9

record for the ship is extracted. In Part II we discussed the importance of this record, noting that if your equipment has not been recorded in the configuration file, then you won't find support for it in your COSAL. At this point the mission essentiality code for each component is also extracted.

Next, the component-to-part record is entered and all parts recorded as being part of each component in your configuration record are identified. Stock number data and technical and maintenance codes for each are extracted. At this point you might reflect back on the technical decision process that produced each code. That process was described in Part I — "The APL." Reference to the figures in that article will help you identify specific codes in the following discussion.

Using the "maintenance code," the list of allowance candidates is selected. Only those items authorized to be replaced onboard are selected as candidates.

These candidates then go through the demand item qualifier program. Taking the total installed part population on the ship (obtained by multiplying the compo-

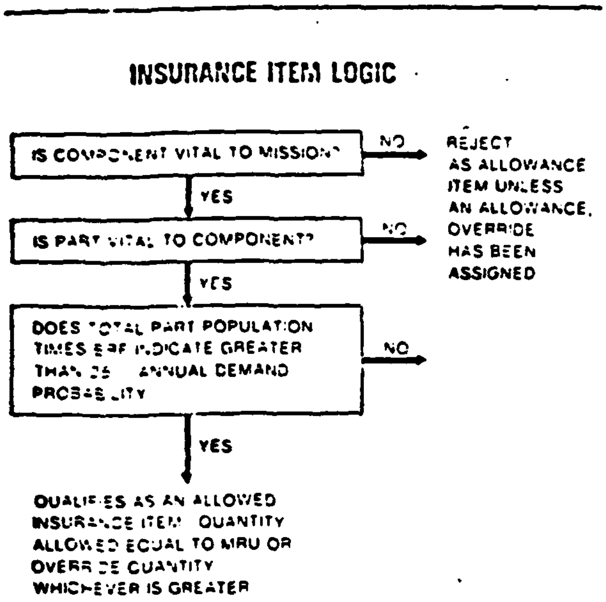


Figure 10

nent population per hull times the part population per component) and multiplying this quantity by the best replacement factor (BRF), it is determined whether the resultant quantity is equal to, less than, or greater than one in 90 days.

If equal to or greater than one in 90 days, the item is classified as a demand-based item. An allowed quantity is computed for each demand-based item which provides a 90% protection level for a 90-day period as required by CNO. If the computed quantity is less than either the minimum replacement unit (MRU) or technical override requirement (TOR), should these be applicable, the highest quantity among these elements is selected as the authorized allowance.

If less than one in 90 days, the candidate is passed to the insurance item program.

Figure 10 depicts the logic utilized for insurance items. First the military essentiality of the components to which the item applies is screened to determine if any of the components are vital to the mission of the ship. This code may be found in your COSAL index. If the components are coded non-vital, the items are rejected unless an allowance override has been assigned. Remember the strict rules governing assignment of these overrides.

If this test is passed, a second screening is performed to determine whether the part itself is vital or non-vital to the component. Non-vital items are again rejected unless an override exists.

The final, and most critical, screening is performed on each remaining item to determine if the part's probability of usage onboard meets or exceeds the CNO criteria for insurance items. A part qualifies if its expected usage, based on the BRF recorded against the FSN (Federal Stock Number) in SPCC's files, exceeds .25 per annum. If it does not meet this criteria it is rejected unless the override exists.

BRF (Best Replacement Factor)

As you can readily see, usage rates play a critical role in determining the repair part allowance for your ship. What few technicians realize is that for all practical purposes they determine the replacement factor for most items. To understand this, let's look closer at the BRF.

The BRF is a usage rate which represents the best estimate of expected annual usage of an item for each installation of that item. When an item first enters the supply system, it is assigned a rate based on an engineering estimate of usage. This rate becomes the BRF until the item has been in the system long enough to establish a demand pattern. The demand development period for this purpose is considered to be one year. Once the item has become established, live demand data are used in conjunction with the technical estimate to compute the BRF. The BRF is then computed as a weighted average which takes into consideration recent demand data, older demand data, and the initial technical estimate of item usage. Recent demand data are used to make the rate responsive to changes in the demand pattern of the item.

The use of older demand data and the initial technical estimate stabilizes the rate and makes it less sensitive to short term variations in demand. Because they are used to compute COSAL (and load list quantities) it is important that the demand data used in the computation of BRFs reflect, as closely as possible, actual ship usage. Several demand data collection systems are utilized. Although the data which is finally selected for use may not be precise, it is considered to be the best available; hence the name best replacement factor.

Three data sources are presently considered as a basis for computing BRFs: 3M (Navy Maintenance and Material Management) usage data; SOAP (Supply Operations Assistance Program) usage data; and ICP Transaction Item Reporting System demand data. The 3M usage data is preferred and is used unless the data base for an item is insufficient.

The BRFs of all shipboard installed repair parts are usually reviewed annually. An item's current BRF will not be updated if the item has been in the supply system less than one year, or the item has less than 5 units installed in the active Fleet, or the item is ordnance protected and the proposed BRF is lower than the existing BRF, or the item's BRF has experienced a large relative increase and a reviewing technician

... not to accept or change it or there is insufficient ... to perform BRF computations.

... system can obtain accurate data only through ... submitted from the ships themselves via the ... commanders. Part usage is recorded as a result ... demands on the supply department and ... "usage only" reporting of maintenance related ... obtained by the technicians from other-than ... sources.

... know that all technicians somehow acquire their ... private stock." For example, few ET shops are ... complete without a selection of common ... tubes, semi-conductors, connectors, etc., in a ... cabinet. We also know that it is not reasonable ... you to live with a due-in document for a ... when the local Norfolk hardware stores ... adequate replacements.

That this is the "real world" is a fact of life. It is ... a sad fact unless you use the parts and don't ... them. Every time this occurs, the BRFs for ... items are diluted. Unfortunately, these are items ... obviously in demand. There are many areas ... the supply-support process that are prone to error. ... this is one place that you can help. By ... understanding and following the relatively simple procedures of OPNAVINST 4790.4, regarding the "Preparation of Internal Supply Documents," you'll have ... satisfaction of knowing that you're improving the ... of your next COSAL and, for that matter, ... COSAL of your sister ships.

Supply Support Improvements Through Re-Provisioning

Occasionally, COSAL and Supply System support ... system is so poor that the Fleet cannot wait ... BRF updates, selected item management, and system demand analysis to gradually improve support. ... stayed with me the last 2 issues, and if ... a believer in "Murphy's Law" (i.e., if something can possibly go wrong, it will!), then you can ... pick as to what event might have caused ... supply support problem. Maybe the wrong ... was used, or maybe the computer set all ... to zero for a few seconds. Regardless of ..., you have a friend that jumps in when a ... of such magnitude is identified: that activity ... Naval Ship Engineering Center, Mechanicsburg ...

... improve supply support to the Fleet, NAVSECMECHDIV has undertaken efforts to improve allowance identification, minimize COSAL shortages ... downtime awaiting parts. The vehicle ... improvements has been a series of re-provisioning conferences. These conferences, sponsored by NAVSEA and hosted by NAVSECMECHDIV, began with a review of support for ACC-FWC (automatic combustion control-feedwater control) systems. Next on the list were improvements for the 1200 psi boilers, forced draft blowers-main feed pump. Efforts are now underway to improve shipboard air compressor support.

Under NAVSECMECHDIV's technical guidance and the dedicated efforts of participants from SPCC, shipyards, NAVSEC and Fleet commands, identification of parts and equipment has been made more simple and direct. This was accomplished by eliminating past oversights and discrepancies in APL part identification numbers and by assuring that all parts listed on a particular APL are referenced to a drawing and piece number which is listed in the appropriate technical manual now held by that ship. Simultaneously, the range of APL insurance items is being expanded. Concurrently, non-metallic items, such as replacement "O" rings, are being increased to enhance system accounting and availability.

NAVSECMECHDIV has also been very active in the various DART Improvement Programs. Included is the 400 Hz generator program and the 1200 psi boiler improvement program. Concerning the latter program, it should be mentioned that NAVSECMECHDIV has conducted highly successful efforts in putting the ACC-FWC and boiler sprayer plates of the Fleet boiler APLs in better array than they have been in some time. APL update studies and improvements on T-MKG torpedo countermeasures, ALCO 251 engine support, fin stabilizers and PG 89/92 have been conducted. Manuals covering temperature measuring thermometers and devices and valve cross-substitutions have been prepared and provided to the Fleet.

Under the scope and tasking of NAVSEA, these efforts are continuing to the extent that existing manpower permits, while present direct funded Fleet services are maintained.

Having recently combined talents with the former NAVSECGLAKES organization, MECHDIV responsibility is no longer limited to the provisioning engineering aspects of machinery and electrical equipment.

The message is simple and direct. If you have a supply support problem, caused by technical inadequacies in your allowance lists for NAVSEA equipment, tell your story to:

OFFICER IN CHARGE
Naval Ship Engineering Center
Mechanicsburg Division
Mechanicsburg, PA 17055

The next article will close out this series. It will deal with the subject of allowance change requests. The scope of that article will be expanded to encompass the world of equipage and its APL counterpart, the AEL (Allowance Equipage List).

SUPPLY SUPPORT - PART 4

The Allowance Change Request

By Mr. D. R. Straub

Naval Ship Engineering Center
Mechanicsburg Division

The first article in this series on supply support discussed the Allowance Parts List (APL) and showed how it is prepared and what it says to the shipboard technician. Other articles explained the importance of establishing and maintaining an accurate configuration record of the equipment onboard a ship, and how the actual COSAL repair part allowances are computed. In this final article of the series we will look at the remaining part of the COSAL, the allowance equipage list (AEL), and in addition, see how the shipboard technician can begin the process of changing the allowance for his ship or getting that much-needed tool or repair part added to the COSAL.

Allowance Equipage Lists

The APL and the COSAL computation described in an earlier article result in onboard allowances being established for the most-often-needed parts to repair equipment installed in the ship's systems. But how do such other items as lifesaving and damage-control gear, office and housekeeping equipment, special and general purpose tools and the many other items, not part of installed systems but still needed for daily operation, find their way into the allowance list and aboard ship? This is the job of the AEL.

An AEL is an allowance list for one item or one family of items needed to perform a specific function. For example, an AEL may list all the office equipment allowed for a ship, may show just one item such as a portable submersible pump and its accessories, or may show a group of related items such as a damage-control locker outfit. The material on AELs is commonly referred to as equipage.

An AEL has 8 columns for allowances of individual items. Different columns of one AEL may apply to many ship types, or quantities for an individual item may vary to provide different allowances in response to some other condition, as we will see later.

It is important to remember several things about the kinds of items shown on AELs. Let's list them and then look closer at each one. AEL material is:

- Usually portable.
- Not part of a ship's installed system.
- Related to a function or purpose.
- Usually not consumable.
- Very often not-stocked material (i.e., not readily available from the Supply System).

Most of the material listed on AELs is portable, although exceptions can be found, and is usually kept in an operating space beyond the control of the supply department. For this reason, department heads usually take custody of the material and the AEL is a record of the material for which the department head is responsible.

Again, exceptions can be found, but most material listed on AELs is not part of a ship's installed system, although many AEL items are closely related to one of the systems, such as firefighting equipment. These items are listed on AELs instead of system APLs because they are ordered separately from the installed equipment, loaded at a different time, and need to be accounted for closely because they can be misplaced or disappear.

Most AEL material is placed aboard ship because some special purpose requires it. Certainly all ships have some firefighting or lifesaving AEL material, but only those ships with steam propulsion would require a boiler-tube cleaning outfit. We see then that features of the ship usually determine the AEL material to be part of the ship's allowance.

A large percentage of AEL material is not of a consumable nature and, therefore, is not frequently replaced nor are spares usually carried. Much of this material is also not carried in the supply system. For these reasons, the AEL contains information describing the non-stocked equipage. The information usually identifies one or more commercial sources, or shows

the physical and operating characteristics needed.

Now that we have seen what an AEL looks like and know generally what sort of material is listed on an AEL, the next question seems to be "So how does an AEL get into my COSAL?" We saw in Parts I and II that APLs get into the COSAL by provisioning, and by the Supervisor of Shipbuilding preparing a mechanized transmittal to be sent to a computer at SPCC. This is done for the equipment shown on the ship's plans and drawings. For equipage, the Supervisor has an even more important part in determining what material should be allowed.

Soon after the start of construction for a new ship, the allowance division of the Supervisor' Office begins the process of deciding what equipage will be required. Certain kinds of equipage will almost automatically be needed, such as lifesaving gear. To determine other requirements, the Supervisor needs to know just what the ship will look like when it is completed. He needs to know what sort of shops will be installed, how many personnel there will be in ship's company, and many other characteristics. These the Supervisor determines from the ship detail specification, manning documents, plans and drawings, and lists of equipment to be installed.

From this information, the Supervisor determines the sorts of equipage and the general types of AELs that will be required. For example, if the specification indicates an internal combustion engine shop is to be installed, the Supervisor knows an AEL containing an outfit of tools for such a shop must be part of the ship's COSAL. As a final check, the COSAL for a ship similar to the one under construction is used as a guide to make sure no type of equipage is overlooked.

After the Supervisor has identified generally the types of equipage required, a decision is made for each item to determine the quantity to be allowed. For this, the Supervisor must determine the method by which individual item requirements are computed. Often individual AELs contain information concerning the computation of allowances.

Let's follow the development of the allowance for an item of equipage to better understand the method used.

Inflatable life preservers are required equipage items aboard nearly every ship type. The AELs for this equipage would, therefore be part of the standard allowance the Supervisor would consider for each ship constructed. The Supervisor would know that AELs in the series numbered 2-33001 would be needed as part of a COSAL being prepared for a ship of the DE-1078 class for example.

To determine the exact number of inflatable life preservers required, the information on a typical AEL, such as 2-330014004 illustrated in Figure 11, would be used. Examination of Figure 11 reveals that inflatable life preservers are to be provided in a quantity equal to 105 % of the ship's complement. Knowing the number in the ship's force, the Supervisor could compute the final required quantity. In our example, assume the ship's complement to be 245. The quantity of inflatable life preservers required would then be 245 $\times$ 1.05 = 257.

Having determined that 257 inflatable life preservers are required, the Supervisor would then select one or more AELs which, using one column from each AEL, would show a quantity of 257. For the example AELs 2-330014001 column 5, 2-330014002 column 4, and 2-330014004 column 2 would be used to show quantities of 5, 42, and 210 for a total of 257. This combination of AELs would then be included in the ship's COSAL, and material from the appropriate column of the AELs ordered for later loading aboard ship.

Requirements for other ships would be computed similarily, although it may be necessary to allow extra life preservers for embarked forces or other personnel likely to be aboard ship. Similarily, requirements for many other equipage items are computed through other perhaps more complicated means, but usually the allowances for equipage are fixed by some characteristic of the ship.

The ACR

Now that we have seen the basic process that first establishes a ship's allowance, let's look at how a ship's force can change its allowance.

We saw in Part III that the shipboard technician, by reporting to the 3M system every time a repair part is used, plays the largest part in determining repair parts' BRFs (best replacement factors). The BRF then is used to compute allowances for repair parts in later ships' COSAL's, increasing them if the BRF indicates greater allowances are needed.

A different procedure is used to correct or update the ship's configuration record, to request the addition or removal of an equipment item, or to request a change in equipage allowances. This procedure is the use of an ACR (allowance change request) as shown in Figure 12.

The ACR (NAVSUP Form 1220 available under Cog I stock number 0108-503-9200) is a 2-purpose form. The top half of the form, blocks 1 and 2, is used to request the replacement of an equipment item or to report the addition or removal of an equipment item if the COSAL is found to be in error.

The lower half of the form, block 3, is used to request the increase or decrease in allowance of an item of equipage and can also be used to request the addition of a repair part that the ship's force believes should be included in the allowance.

ALLOWANCE EQUIPAGE LIST (AEL)

LIFE PRESERVER CO2 IFL FOR 100-500 MEN — TECHNICAL DOCUMENT NUMBER — 2-330014004 03-30-74 1

INFLATABLE LIFE PRESERVERS AND ACCESSORIES
SPECIFICATION MIL-L-15551
TOTAL ALLOWANCE OF INFLATABLE LIFE PRESERVERS TO BE
105 PERCENT OF SHIPS PERSONNEL ACCOMMODATIONS
ONE COMPLETE SET OF ACCESSORIES FOR EACH LIFE PRESERVER
TWO SPARE LAMPS FOR EACH DISTRESS LIGHT
THREE CO2 CARTRIDGES ALLOWED FOR EACH INFLATABLE LIFE
PRESERVER
ONE REPAIR KIT ALLOWED FOR EACH 100 INFLATABLE LIFE
PRESERVERS
IF INDEX ALSO INCLUDES ADDITIONAL AELS FOR THIS MATERIAL
WITHIN THE FOLLOWING SERIES OF NUMBERS 2-330014001
THRU 2-330014012 ADD QUANTITIES FROM APPLICABLE
COLUMNS FOR TOTAL SHIPS ALLOWANCE
SEE INDEX PART 1 FOR COLUMNS WHICH APPLY
COLUMN 1-FOR 100 MEN
COLUMN 2-FOR 200 MEN
COLUMN 3-FOR 300 MEN
COLUMN 4-FOR 400 MEN
COLUMNS 5 TO 7-BLANK
COLUMN 8-FOR 500 MEN
FSCM-03350

Reference No./Descriptive Data	Item Name	Stock No.			U/I	Col 1 2 3 4	Col 8
ONE PER LIGHT	BATTERY-DRY BA30U	9Y 6135-120-1020	UPA	ZC	1CPG	5 10 14 19	23
SEE NOTE ABOVE	CARTRIDGE-CO2	9C 4220-372-0555	JPA	ZC	1EEA	315 630 945 AR	1575
SPARES FOR STORE ROOM	LAMP-INCDT TY TB16	9G 6240-155-6669	UPA	ZC	REA	220 440 660880	1100
YOKE TYPE SEE NOTE	LIFE PRESERVER-YOKE IFL	9C 4220-283-1891	UPA	ZC	1LEA	105 210 315420	525
110% PERS ACCOD	LIGHT-MKR DTRS	9G 6230-255-0166	JPA	GR	1EEA	110 220 330440	550
MIL-R-16417 SEE NOTE	REPAIR KIT-MINSELL RED	9[illegible]-694-1410	UPA	Z	1EEA	AR AR AR AR	AR
110% PERS ACCOD	SEA MARKER-FLRSNT	9G [illegible]-270-9956	UPA	ZC	1EPZ	110 220 330440	550
MILW10537TYPE1	WHISTLE-B WLNYD	9DM8465-254-8803	UPA		1EEA	110 220 330440	550

END

REFERENCE NO./DESCRIPTIVE DATA — ITEM NAME — STOCK NO. — 1 2 3 4 5 6 7 8

ALLOWANCE EQUIPAGE LIST (AEL) — 2-330014004 03-30-74 1

SHIP TYPE & HULL NO. PAGE — IDENTIFICATION NO. DATE PAGE

Figure 11

Let's first look at use of the form to request addition of an equipment item or to report an equipment item actually onboard and not included in the COSAL. In either case, information about the equipment is needed. If the equipment is actually installed, copy the nameplate data into the blocks on the form, and check the block that says "New C/C." The important thing is to provide as much information about the equipment as possible so it can be identified to an APL, and include the location and system application. Mail the form to

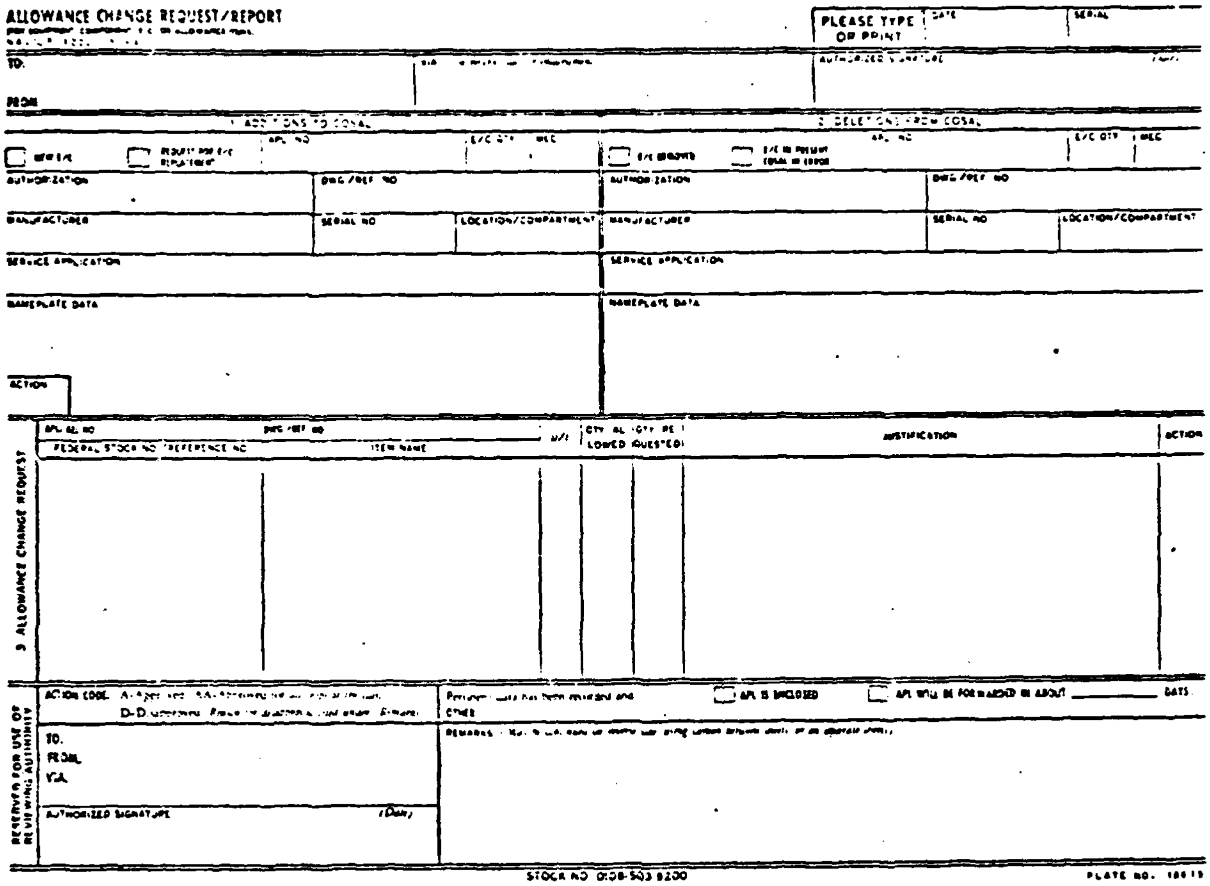
Commanding Officer
Ships Parts Control Center
Mechanicsburg, PA 17055

so your COSAL can be updated. The same procedure should be followed using block 2 to report equipment that has been removed or to correct the COSAL if it shows equipment that is not actually installed.

The most common use of the ACR is to request some change in allowance for one or more items of equipage. For this purpose block 3 would be used. The information required by block 3 is pretty simple, but the most important part is the justification. After your ACR is completed, forward it through command channels to the office that has to finally review the request and approve or disapprove it. Generally, that office is the

Naval Ship Engineering Center
Mechanicsburg Division
Mechanicsburg, PA 17055

Other offices may be involved for electronic test and measuring gear, ordnance and nuclear propulsion equipage, and other special categories of equipment. If you prepare an ACR and are uncertain to what office it should be sent, address it to NAVSECMECH and it will be forwarded to the appropriate command.


ALLOWANCE CHANGE REQUEST/REPORT

PLEASE TYPE OR PRINT

TO:

FROM

AUTHORIZATION

MANUFACTURER

SERIAL NO

LOCATION/COMPARTMENT

SERVICE APPLICATION

NAMEPLATE DATA

ACTION

JUSTIFICATION

3. ALLOWANCE CHANGE REQUEST

RESERVED FOR USE OF REVIEWING AUTHORITY

TO.

FROM.

VIA.

AUTHORIZED SIGNATURE

STOCK NO 0108-503-8200

Figure 12

Now let's see what happens when an ACR is received at NAVSECMECH. Assuming the ACR is complete, has been properly endorsed by the Type Commander, and contains enough information to be processed, the ship's present allowance for the item is determined. Many times it is found that an allowance has already been changed without the ship being notified and the ship is notified accordingly. If it is found that the ship is not presently allowed the item or it is not allowed in the quantity requested, the NAVSECMECH technician determines whether the ship should be allowed to carry the item and if so what the proper allowance should be.

It is here that the justification provided by the ship making the request is so important. If the item is one like the life preservers used in the earlier example, and the present allowance is considered proper according to the rules for computing the number required, the request will likely be disapproved unless the justification provides a good reason for authorizing an increase. In this case, the allowance increase would probably be made for every ship in a class, possibly a ship type, or if the basic method of computing the requirement is changed, perhaps every ship carrying the item will be granted an increase.

Certainly not every item a ship carries is allowed as a result of a computation such as was illustrated. It is recognized many items of equipage are desired because of a particular operational or maintenance technique used by the ship's force, or because it represents a convenience or saves time. If an increase in allowance is desired for this reason, the justification should indicate just that.

One final word about why an ACR might be disapproved. Remember that much of a ship's equipage is used by ship's force for routine day-to-day operation. As a result shipboard personnel are exposed to a certain hazard if the requested item is not electrically safe, mechanically able to stand the strain of shipboard use, or is judged unsuitable for its intended use. If at all possible in the event a request for a particular item is disapproved, a suitable, safe substitute will be identified and its use suggested.

18

RELIABILITY APPROACH TO THE SPARE PARTS PROBLEM

George H. Ebel and Andrew J. Lang
Fairchild Camera and Instrument Corporation
Defense Products Division
Clifton, New Jersey

Summary

A system has been developed whereby unskilled personnel, using simple charts and tables, can select the number of spare parts required to support a given program.

The detailed method of programming a digital computer to generate the charts and tables is presented. Information is generated for various confidence limits, operating times and failure rates. Typical cases are presented for the use of these charts and tables. These include:

1. Selection of minimum spares requirements for a given program.

2. Determination of critical spares after program has been running for some time. Basically this operation is a check on original failure rate assumptions in time to take corrective action before a system is out of service due to the lack of a spare part.

3. Action to be taken if a spare part is determined to be critical.

Planned future efforts in the reliability approach to the maintenance problem are discussed. These efforts include more parameters than have been considered in this paper. The goal of the next phase of the program is to be able to feed parts lists, operating times, use conditions, etc. into the computer and have the computer print the most economical solution to the spare parts problem. This solution would include such things as the original order for spare parts, the intervals at which various spares should be checked, and the proper action to be taken for the number of spares in stock at the time of the inventory.

Introduction

In the last eight years the method of predicting reliability using failure rates of individual piece parts has grown from an experimental toy to a standard tool in systems design and development. Since one step in the prediction of reliability results in establishing the expected failures for a system in a given time period, it would seem logical to tie the spare parts requirements to the same basic method. Therefore, a program was originated which would make use of component failure-rate data to calculate both the equipment reliability and spare parts list for any given project. The goal of the program is to feed information such as the parts list for the equipment, environmental conditions, number of equipments, the duration of the program, etc. into a digital computer and have the computer print out the expected mean time between failures for the equipment, the ten components contributing most to the failure rate, and a recommended spares list to support the project. Such a program would allow rapid comparison of various approaches to the solution of the problem at hand.

In the process of developing the subroutines necessary for the overall program, a series of charts were produced which appeared to be useful tools in the solution of certain spare parts problems. These charts are useful, not because of any basically new material, but as a result of the form in which the material is presented. They allow unskilled personnel to prepare a spare parts list, and, after the program has been running for a period of time, to determine which spares are critical.

Generation of the Charts

The charts were developed while generating a subroutine to find the minimum number of spares required to meet some pre-determined confidence level, given the operating time and failure rate of the item in question. The failure times for component parts of relatively complex systems are generally found to be exponentially distributed and, therefore, the Poisson Formula would apply.

$$P_n = \frac{\left(\frac{t}{\bar{T}}\right)^n}{n!} e^{-\left(\frac{t}{\bar{T}}\right)}$$

Where P_n = probability of having n failures in time t

$\bar{T}$ = mean-time-between-failures

t = operating time

Since failure rate, as opposed to mean-time-between-failures, is generally encountered, we can, by using the equation

$$\text{Failure rate} = \lambda = \frac{1}{\bar{T}}$$

redefine the expression for P_n as follows:

$$P_n = \frac{(\lambda \times t)^n}{n!} e^{-(\lambda \times t)}$$

where as before

P_n = probability of having n failures in time t

t = operating time

and

λ = failure rate

Now define the cumulative probability $P_c(r)$ as the probability of having r or less failure in time t.

$$P_c(r) = \sum_{n=0}^{r} P_n$$

Since $P_c(r)$ is the probability of having the number r or less failures of a particular item with a given failure rate during the time interval t, this also becomes the probability of having adequate replacement parts available if at the beginning of the period there were r replacement parts for this particular item in stock. In other words, if a desired cumulative probability is given for a particular item, the number of pieces needed for spares can be determined by summing the values of the individual probabilities of failures until this sum is equal to or greater than the desired cumulative probability. The current working value of n will then be the number of items which must appear as spares at the beginning of some time interval t to ensure the desired part availability. The flow chart shown in Figure 1 and described below was used to generate the data for the charts.

Description of the Flow Chart

Box 1: Input data to program is entered.
λ is the failure rate per million hours
t is the operating time in months
P_1 is the desired probability or confidence level for the chart being generated.

Box 2: The ratio $\frac{t}{\bar{T}} = \lambda t$ is calculated. The constant 730. x 10^{-6} converts time in months to time in hours and adjusts failure rate per million hours to failure rate per hour.

Note: The number of hours per month is taken as 730.

Box 3: The exponential $e^{-(\lambda t)}$ is calculated.

Box 4: N, the number of spares required, is initialized to zero.

Box 5: P_2, the probability of having N failures, and P_3, the probability of having N or less failures, are initialized to the value of the exponential.

Box 6: If the cumulative probability P_3 is greater than or equal to the desired probability, the results are printed. If not, the next iteration is executed.

Box 7: Increment N by one

Box 8: Compute a new value for P_2, the probability of having N failures.

Box 9: Compute a new value for P_3, the probability of having N or less failures.

Box 10: The probability of having N or less failures, P_3 and N are printed.

The only subroutine needed to execute the program is an exponential routine. Since the value of the exponential may fall into a large range, a subroutine, which will maintain sufficient accuracy throughout this range, is required. A suggestion for computing the anti-logarithm is to use a Hastings

Approximation[1] for 10^x. The argument is initially multiplied by log e and then divided into an integral and a fractional part. The integral part becomes the characteristic of the result: the fractional portion is evaluated in the polynomial to produce the mantissa. When the argument of the function is positive, the error in the result for an eight digit mantissa does not exceed one in the last digit of the mantissa. When the argument is negative, e^x is evaluated as $\frac{1}{e^{|x|}}$ the limit of error is one in the next to last digit of the mantissa because of the additional truncation that may occur when taking the reciprocal.

The following example shows how one point for the 12 month curve of the 99% confidence level was obtained.

<u>Sample Problem</u>

Box 1 = 30. Failures/million hours
t = 12 months
P_1 = .99 confidence level

Box 2 R = .262800

Box 3 E = .768896

Box 4 N = 0

Box 5 P_2 = .768896

$P_3(0)$ = .768896

Box 6 $P_3(0)$ is not greater than P_1

Box 7 N = 1

Box 8 .202066

Box 9 .970962

Box 6 $P_3(1)$ is not greater than P_1

Box 7 N = 2

Box 8 .026551

Box 9 .997513

Box 6 $P_3(2)$ is greater than P_1

Box 10 $P_3(2)$ = .997513

N = 2

The charts for 50, 75, 90, 95 and 99% confidence levels were plotted and appear in Figures 2 through 6.

Use of the Charts

The charts presented in the preceding section were developed to allow unskilled personnel to perform two basic operations associated with spare parts control. The first operation is used to determine the number of spare parts required to support a program for a specified period of time at a specified level of confidence. The confidence level is the probability that there will be adequate spares for the specified period of time. The second operation is used to determine the critical spares after the program has been running for some time. Both of these operations make use of the failure rates of the parts making up the system.

Table I presents a set of failure rates that has given satisfactory results. However, any set of failure rates (based on constant failure rate assumption) that has proven satisfactory for predicting reliability could be used in conjunction with the spare parts charts.

As noted at the bottom of Table I, certain items have predictable wearout life which may be shorter than the expected operating time of the equipment under consideration. The replacement parts required due to normal wearout should be added to the spares complement determined by using the spare parts charts.

Requirements determined by these charts need not be confined to piece parts. Spares for any item (from piece part to complete system) which has a random failure pattern can be determined using the charts.

The basic procedure for determining the spares required is as follows:

<u>Step I</u> Determine the applicable failure rate for the part, component, assembly, etc., under consideration (See Table I)

<u>Step II</u> Determine the number of times the part (component, assembly, etc.) is used in

equipment to be serviced by the supply point, i.e., the number of times the item is used in a system times the number of systems serviced by the supply point.

<u>Step III</u> Enter the left-hand side of the chart at the value determined in Step I.

<u>Step IV</u> Move up the sloped line until it intersects the vertical line determined in Step II. This determines the total failure rate for the items for a particular supply point.

<u>Step V</u> Move horizontally to the curve of operating time for the item. Operating time is determined by multiplying the length of the program (calendar time) by the fraction of the time the equipment is turned on.

<u>Step VI</u> Move down to the abscissa to determine the number of spares required.

The basic procedure for determing the critical spares after the program has been running for some time is as follows:

<u>Step I</u> Locate the point on the chart at which the original spare quota was determined i.e., the intersection of the operating time curve and the spare parts initially required.

<u>Step II</u> Move horizontally to the left until the curve of expected operating time remaining in the program is reached.

<u>Step III</u> Move down to the abscissa to determine the minimum spares which should still be in stock for the applicable confidence level.

<u>Step IV</u> Compare the number in stock with that determined in Step III. If the number in stock is less than that determined in Step III, then the item is in a critical condition.

After a spare has been established as critical, the problem arises as to what action should be taken. For a spare to be in a critical condition either the original estimate of failure rate was too low or the parts are being used up faster than expected due to statistical variations associated with the random failure process. The original failure rate assigned to the part is usually based on a considerable amount of past history and therefore the hypothesis that the original failure rate is correct should not be rejected unless there is substantial evidence to reject the hypothesis.

If the number of failures occuring in the time interval in question is such that there is less than a 10% chance that the true failure rate could be as low as estimated, then it would seem reasonable to recalculate a new failure rate for that part and increase the spares accordingly. This means that one time out of every ten we would be ordering more parts than necessary to support the program at the original confidence level. Based on the foregoing discussion the following procedure can be established for action to be taken if a spare is determined to be in a critical state:

1. Enter the 90% confidence level chart at the original failure rate and move up the sloped line to the intersection of the vertical line representing the number of times the item is used in equipment serviced by the supply point. Move horizontally to the operating curve determined by the operating time of the equipment from the beginning of the program to the time of the stock check.

2. Move down to the abscissa to determine maximum number of spares that could be used in the time interval before the failure rate for that part should be recalculated.

3. If the number actually used is less than the number determined in Step 2, then go back to Step III of "the basic procedure for determining the critical spares after the program has been running for some time" to determine the number of spares required to support the program at the proper confidence level.

4. Order the difference between the number actually left in stock and the number determined in Step 3.

5. If the number actually used is <u>more</u> than the number determined in Step 2 then a new failure rate should be calculated using the following formula:

$$\lambda_n = \frac{N \times 10^6}{nt_o}$$

Where λ_n = new failure rate

N = number of spares used in the time interval from beginning of program to time stock is checked

n = number of times the part is used in equipment serviced by the supply point

t_0 = time interval in hours (assume 730 hours in a month)

6. Using the new failure rate and the operating time left in the program, determine the number of spares required to support the program at the proper confidence level. (Use "the basic procedure for determining the spares required")

7. Order the difference between the number actually left in stock and the number determined in Step 6.

Examples

The following three examples are presented to show several typical cases for the use of the spare parts charts.

1. Selection of minimum requirements for a given program in which all spares are ordered at the start of the program.

2. Determination of critical spares after the program has been running for some time.

3. Action to be taken in the case of critical spares.

Example I

Assume an Aircraft Carrier Supply Officer wanted to have enough spares on board to service 20 airborne oscilloscopes for a three year period. The requirement was established that there be a 95% assurance that at least one spare of each part would be available, at the end of the three year period. The operational duty cycle for the oscilloscopes was set at an average of sixteen hours a day (or twenty-four months out of thirty-six) for each scope.

For this example the problem is to determine the number of spare cathode ray tubes required to satisfy the requirements stated above.

The first step is to locate the proper failure rate for cathode ray tubes used in a manned aircraft envir.nment. Table I lists this as sixty. Next select the chart for 95% confidence level and enter the chart on the left hand side at a failure rate of sixty. Move up the slanted line until it intersects the vertical line marked 20 (the number of scopes to be serviced at the repair point). This will determine the total failure rate for the twenty cathode ray tubes. Now move horizontally to the right until the operation time curve for twenty-four months is reached and then down to the abscissa to determine the number of spares required. In this case the absicca is intersected between twenty-seven and twenty-eight so twenty-eight tubes are required.

Example II

The officer in charge of supplies in the first example must know if any spare parts are in a critical situation in time to procure new spares before the supply is exhausted. In other words he should have a method for reviewing his stock at any point in the program and quickly selecting those items which are in a critical state. For this example let us assume that the program in Example I has been running for eighteen months and has eighteen months left to run. This would mean that there is an average of twelve months of operation time left for each oscilloscope. The problem is to determine if enough cathode ray tubes are in stock to safely complete the program without re-ordering. In this case we enter the chart at the intersection of the initial operating time curve (twenty-four months) and the spares in stock at the beginning of the program (twenty-eight). Now move horizontally to the left until the twelve month operation time cure is intersected. Then move down to the abscissa to determine the minimum number of spares which should be in stock for a given confidence level to complete the program without re-order. In this case, there should be at least sixteen tubes in stock. If there are more than sixteen tubes in stock, then the spares situation is not critical. If there are less than sixteen tubes in stock, the action to be taken would hinge on the number of spares used in the first 12 months of operation.

Example III

Assume that 16 cathode ray tubes had been used in the first half of the program described in examples I and II. This means that only 12 remained in stock, and the spares are in a critical condition.

To determine if the failure rate of 60 for the cathode ray tube should re recalculated, the 90% confidence chart is entered at 60. Move up the sloped line until the vertical line for 20 units is intersected. Next move horizontally to the operating time curve for 12 months, and then down to the abscissa to determine the number which would not be exceeded more than 10% of the time if 60 were the true failure rate. In this case, the number is fifteen. Since 16 tubes were used, the failure rate should be recalculated as follows:

$$\lambda_n = \frac{N \times 10^6}{nt_o} = \frac{16 \times 10^6}{20 \times 12 \times 730} = 91$$

With a new failure rate of 91 for 12 months operating time left in the program, the spares required for a 95% confidence level is 22 (determined following basic procedure for determining the spares required as in example I). Since there are still 12 tubes in stock, 10 tubes will have to be ordered.

Future Program

The next step in the program is to prepare a set of IBM cards containing basic information on the component parts used in fabricating electronic equipment. This would include the failure rates for various combinations of environments which the part may encounter. The normal lead time expected for ordering, the cost (including quantity discounts) and a list of qualified suppliers.

The program is being developed to handle such input parameters as:

1. Environmental conditions the equipment will encounter.
2. Duration of program.
3. Various confidence levels
4. Number of equipments (both total and per supply point).
5. Various reordering periods.
6. Minimum acceptable probability of having a part in stock when required.
7. Effects of not having a spare when needed.
8. Parts list for the equipment.

The output of the computer will include:

1. Expected failure rate of the equipment.
2. The components with the highest failure rates.
3. Spare parts list to support the program.
4. Cost of aspects of a specific set of conditions.

One of the major uses for the program outlined above will be to determine the effect of various approaches to a problem on the overall system adequacy. This can be accomplished rapidly and early enough in the equipment development cycle to allow basic design decisions to reflect both reliability and maintenance considerations.

References

1. Hastings, Jr., C. "Approximations for Digital Computers" Princeton, New Jersey; Princeton University Press, 1955, Page 144

TABLE 1

FAILURE RATES PER MILLION HOURS

Component	Laboratory	Ground Station	Shipborne	Trailer Mounted	Manned Aircraft	Ground Checkout of Missileborne: Ample Space	Ground Checkout of Missileborne: Limited Space
Capacitors							
General	.010	.011	.080	.170	.30	.20	1.0
Electrolytic	.150	.165	1.200	2.550	4.50	3.00	15.0
Ceramic	.100	.110	.800	1.700	3.00	2.00	10.0
Tantalum	.100	.110	.800	1.700	3.00	2.00	10.0
Delay Lines							
Fixed	.150	.165	1.200	2.550	4.50	3.00	15.0
Variable	3.000	3.300	24.000	51.000	90.00	60.00	300.0
Electron Tubes							
Cathode Ray	2.000	2.200	16.000	34.000	60.00	40.00	200.0
Gas Regulator	1.000	1.100	8.000	17.000	30.00	20.00	100.0
Klystrons	3.000	3.300	24.000	51.000	90.00	60.00	300.0
Magnetrons*	100.000	110.000	800.000	1,700.000	3,000.00	2,000.00	10,000.0
Power	10.000	11.000	80.000	170.000	300.00	200.00	1,000.0
Power Pulsers*							
Hard Tube	30.000	33.000	240.000	510.000	900.00	600.00	3,000.0
Soft Tube	150.000	165.000	1,200.000	2,550.000	4,500.00	3,000.00	15,000.0
Receiving	2.000	2.200	16.000	34.000	60.00	40.00	200.0
Thyratrons							
Power	15.000	16.500	120.000	255.000	450.00	300.00	1,500.0
Receiving	5.000	5.500	40.000	85.000	150.00	100.00	500.0
Traveling Wave	3.000	3.300	24.000	51.000	90.00	60.00	300.0
Inductors	.020	.022	.160	.340	.60	.40	2.0
Jacks & Plugs (Per Connection)	.001	.001	.008	.017	.03	.02	.1
Lamps							
Incandescent	8.000	8.800	64.000	136.000	240.00	160.00	800.0
Neon	1.000	1.100	8.000	17.000	30.00	20.00	100.0
Motors & Synchros*	.150	.165	1.200	2.550	4.50	3.00	15.0
Quartz Crystals	.100	.110	.800	1.700	3.00	2.00	10.0
Relays (Sealed)*							
General Purpose	.250	.275	2.000	4.250	7.50	5.00	25.0
Miniature	.060	.066	.480	1.020	1.80	1.20	6.0
Resistors							
Fixed Film	.026	.029	.208	.442	.78	.52	2.6
Fixed Comp.	.015	.017	.120	.225	.45	.30	1.5
Wire Wound	.150	.165	1.200	2.550	4.50	3.00	15.0
Variable							
General	.200	.220	1.600	3.400	6.00	4.00	20.0
Computing	5.000	5.500	40.000	85.000	150.00	100.00	500.0
Semiconductors							
Diodes							
Germanium	.300	.330	2.400	5.100	9.00	6.00	30.0
Selenium	.300	.330	2.400	5.100	9.00	6.00	30.0
Silicon	.100	.110	.800	1.700	3.00	2.00	10.0
Zener	.150	.165	1.200	2.550	4.50	3.00	15.0
Transistors							
Germanium	.600	660	4.800	10.200	18.00	12.00	60.0
Silicon	.200	.220	1.600	3.400	6.00	4.00	20.0
Switches* (Per Contact Set)							
General	.500	.550	4.000	8.500	15.00	10.00	50.0
Micro	.100	.110	.800	1.700	3.00	2.00	10.0
Rotary	.175	.191	1.400	2.975	5.25	3.50	17.5
Transformers							
General	.020	.022	.160	.340	.60	.40	2.0
Pulse	.100	.110	.800	1.70(	3.00	2.00	10.1

*These items have predictable wearout life which may be shorter than the expected operating time of the equipment under consideration. The replacement parts due to normal wearout should be added to the spares complement determined by using a random failure assumption.

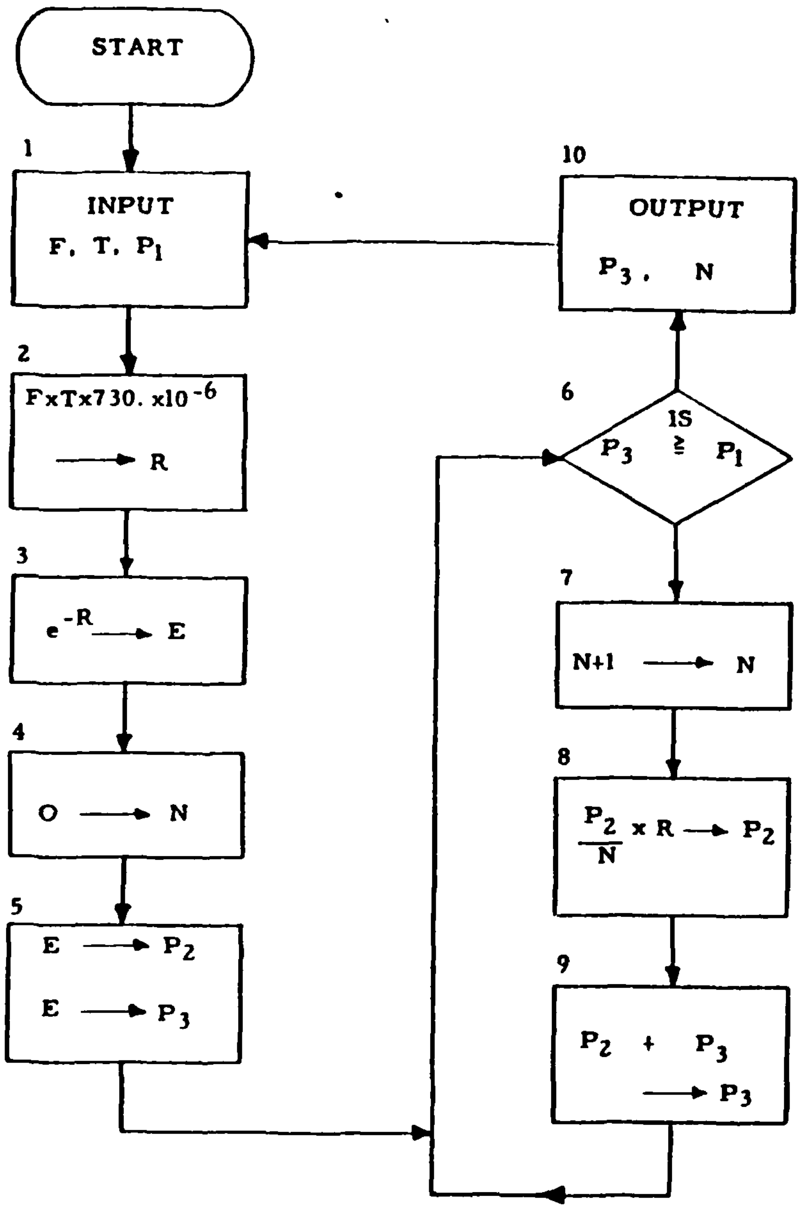


FIGURE 1

PROGRAM FLOW CHART

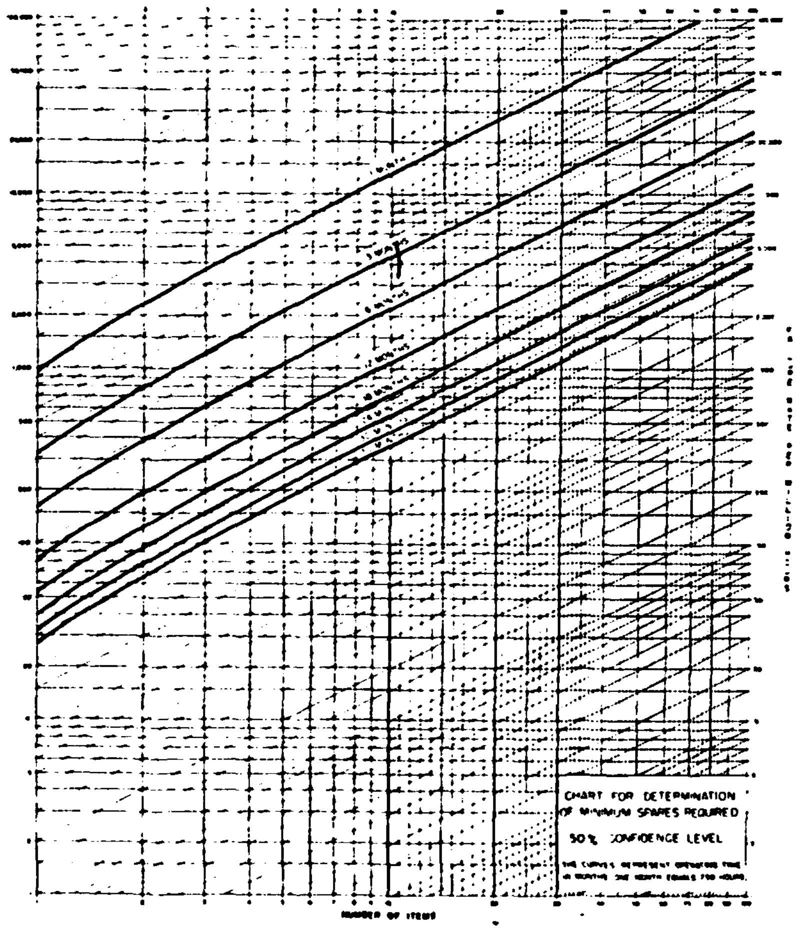
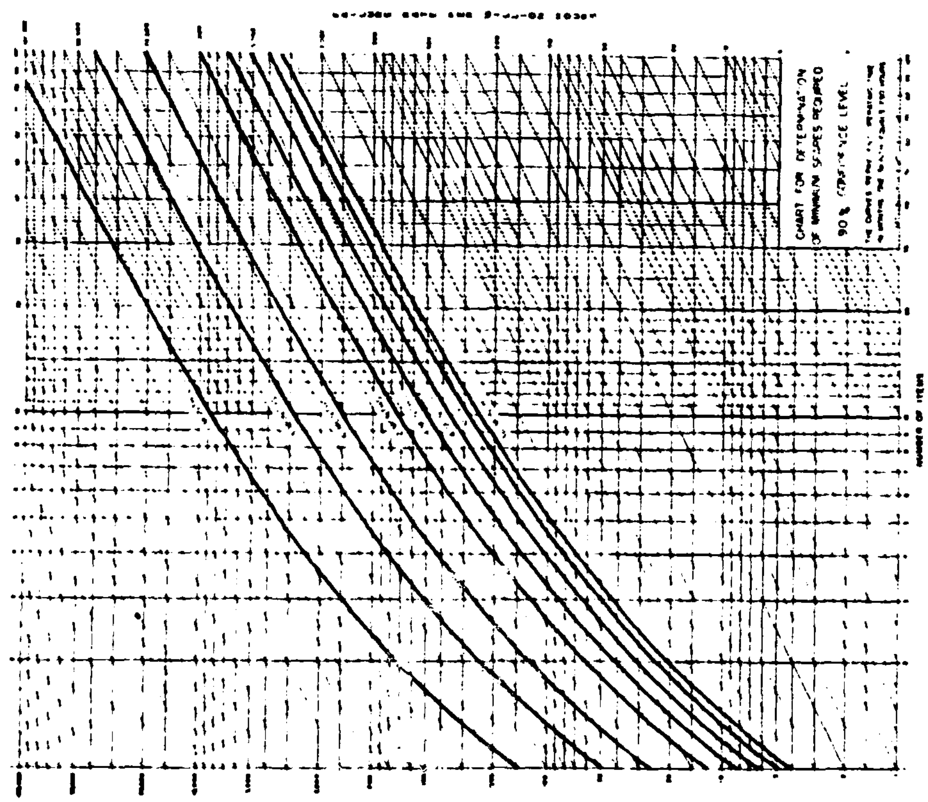


FIGURE 2



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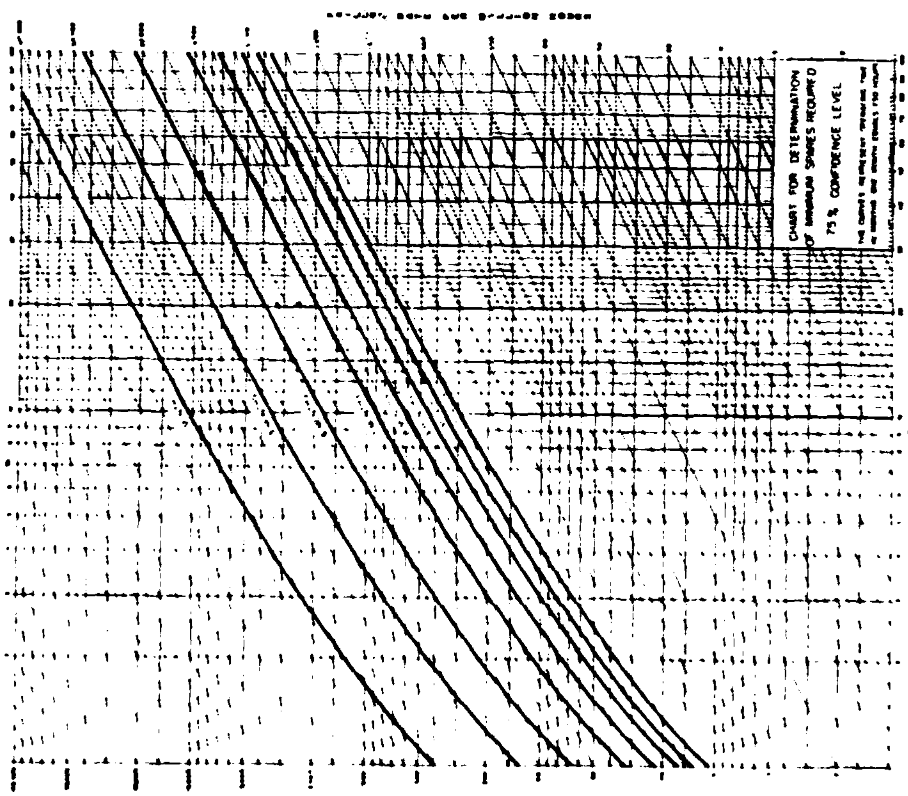
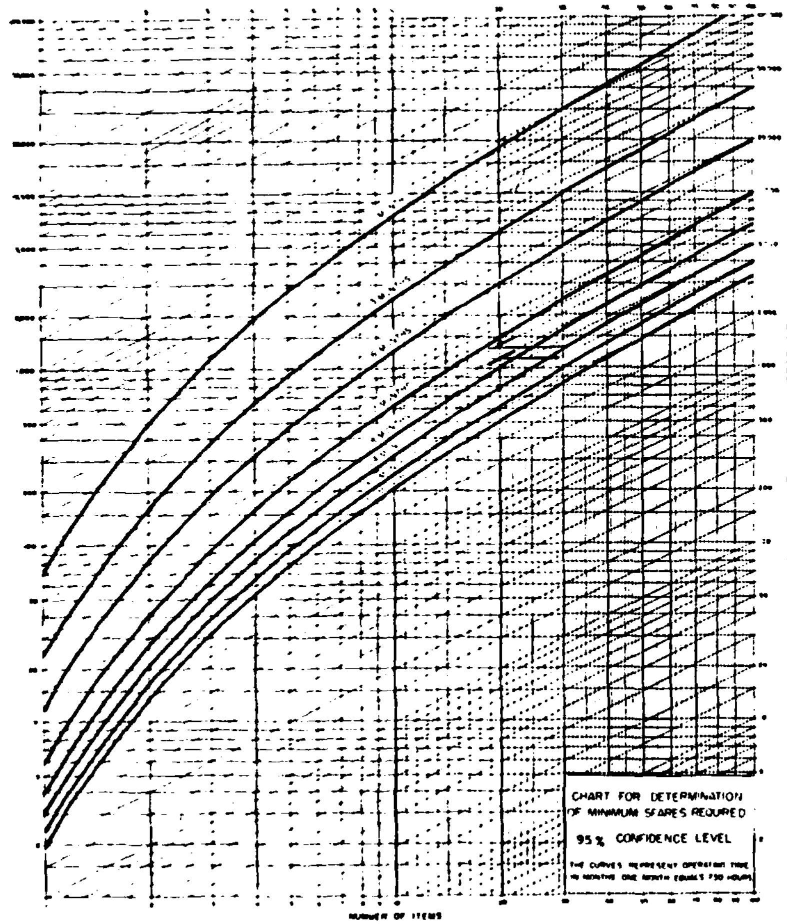


FIGURE 3



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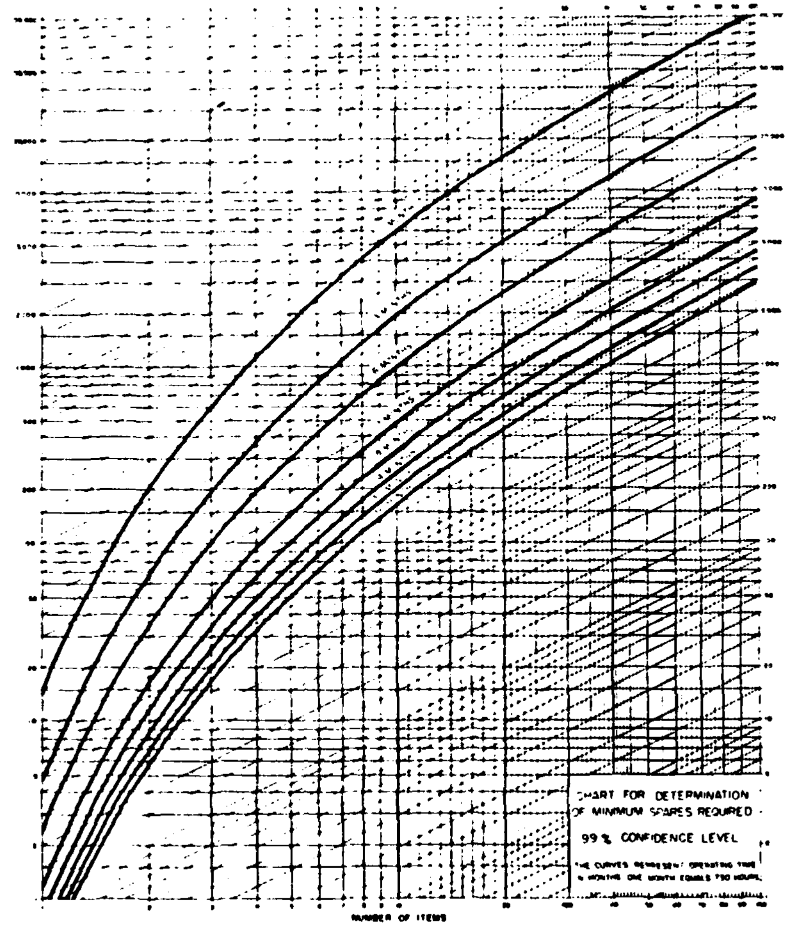

FIGURE 6

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OPERATIONS RESEARCH, Vol. 7, 1959

ON OPTIMAL REDUNDANCY†

Guy Black and Frank Proschan

Electronic Defense Laboratory, Sylvania Electric Products, Inc., Mountain View, California

(Received March 2, 1959)

A complex system is to be placed in the field for a fixed period. During the period only the spares initially provided may be used to replace components that have failed. Independence of failures is assumed among the essential components considered. Given the cost of components, the number of like components of each type simultaneously operating, the length of operation scheduled for each component, the failure distributions of components, a general mathematical solution is obtained for the composition of the spare parts kit which maximizes assurance of continued operation during the period, subject to a fixed budget for spares. Explicit formulas are obtained in the case of exponential failure distributions, constructive procedures in the case of monotone likelihood ratio densities. Fortunately, the identical mathematical model is applicable in determining the optimal allocation of redundancy in designing system reliability under a weight or cost restraint.

CONSIDER these two seemingly different problems, one arising in inventory control, the other in reliability design:

1. A complex system is to be placed in the field for a period of experimentation. How many spares for each of the essential components should accompany the system? Maximum assurance of continued operation of the system is desired for a fixed expenditure for spares. Component failure distributions are known.

2. A complex system (a missile, say) is to perform a mission. How should redundancy be designed into the system to give maximum reliability within the weight limitation? Component failure distributions are known.

Actually, both problems have the same mathematical structure under certain assumptions. In this paper, we show how we may solve these problems.

Related models in the spare parts problem have been treated by GEISLER AND KARR[4] and GOURARY.[5,6] In these models, the expected total of weighted shortages is minimized subject to a linear weight or cost restraint, with the demand probability density for spares assumed a priori. In our first (second) model, we maximize assurance of continued system operation (reliability) by optimal allocation of spares (redundant units) likewise subject to a linear restraint, but with the demand for spares (redundant units),

† Presented at the Fifteenth National Meeting of the OPERATIONS RESEARCH SOCIETY OF AMERICA, Washington, D. C., May 14, 1959.

instead of being assumed a priori, *generated by failure of operating units* following known probability distributions. Thus, to obtain the composition of the optimal spare parts kit in the first model we use information about component failure rates rather than information about component demand distributions. In the typical situation under consideration—a new system under experimentation for a single period in the field—we are thus given the opportunity to use information we may have, component failure rates, rather than be called upon to provide information we may not have, component demand distributions.

Our choice of assurance of continued system operation as the figure of merit to be maximized is especially relevant in military applications, where a penalty cost is often difficult to determine. In the system reliability model (Model 2 above) especially, probability of successful system operation is a completely natural choice for the figure of merit.

MATHEMATICAL MODEL—EXPONENTIAL LIFE DISTRIBUTION

A SYSTEM is to be placed in the field for a fixed period t_0 of experimentation. During the period only the spares initially provided may be used to replace components that have failed. Independence of failures is assumed among the components considered. Only essential components are considered. The system consists of d_{ij} components of type i, scheduled for t_j hours of use, $j=1, 2, \cdots, m$. A single unit of type i costing c_i, has an exponential life density $\mu_i \exp(-\mu_i t)$, with failure rate per hour of μ_i, $i=1, 2, \cdots, k$.

What choice of n_i, the number of spares provided of the ith type, $i=1, \cdots, k$, will yield maximum assurance of adequacy of spares for each of various values of the cost $c=\sum_{i=1}^{i=k} n_i c_i$?

Note that an analogous statement describes the reliability design problem: Substitute 'redundant standby units' for 'spares,' and in cases where weight is the key consideration, rather than cost (e.g., missile design), substitute 'weighing' for 'costing' and 'weight' for 'cost,' and finally, 'reliability' for 'assurance of adequacy of spares.' Assume that any standby units present are not actually in use, and therefore have no probability of failure during standby; and that switching in of a redundant unit occurs with perfect reliability and unimpaired performance. The problem is then the same. For simplicity of presentation, we will discuss the problem in terms of the spare parts model.

To solve the problem, we first define

N_{ij} = number of failures during the t_j hours of operation.

N_i = total number of failures of type i during the t_0 hours.

Then N_{ij} is a Poisson random variable with parameter $\mu_i d_{ij} t_j$.[1] Since $N_i=\sum_{j=1}^{j=m} N_{ij}$, then N_i is a Poisson random variate with parameter $\lambda_i=\mu_i \sum_{j=1}^{j=m} d_{ij} t_j$.[3]

Next define:

$P_i(n_i)$ = probability that n_i spares of type i will be adequate,

$n = (n_1, \cdots, n_k)$

$P(n)$ = probability that a spare parts kit consisting of n_i spares of type i, $i = 1, \cdots, k$, will be adequate.

By adequacy we mean, of course, that during time t_0, the number of spares needed will be at most the number provided. Thus, in the present case of underlying exponential life distributions,

$$P_i(n_i) = \Pr[X_i \leqq n_i] = \sum_{x=0}^{x=n_i} \exp(-\lambda_i)/(\lambda_i^x/x!). \qquad (1)$$

Because of assumed independence of operating components,

$$P(n) = \prod_{i=1}^{i=k} P_i(n_i). \qquad (2)$$

We wish to maximize $P(n)$ subject to

$$c(n) = \sum_{i=1}^{i=k} n_i c_i \leqq c_0 \quad \text{and} \quad n_i \geqq 0. \qquad (i = 1, \cdots, k) \quad (3)$$

Define $R_i(n_i) = \ln P_i(n_i)$ and $R(n) = \ln P(n)$. Then, it is equivalent to maximize $R(n)$ subject to (3).

Maximizing a nonlinear function $R(n)$ subject to linear restraints (3) is a special case of nonlinear programming, treated by Kuhn and Tucker.[11] In their article, the theorems are developed in detail for continuous variables. In our problem, we are dealing with discrete variables, $n_1, \cdots, n_k$. Thus we shall independently derive theorems which are alternately derivable by the methods of Kuhn and Tucker.

First we need:

Lemma 1: *$\Delta R_i(m) = R_i(m+1) - R_i(m)$ is a decreasing function of m for $i = 1, \cdots, k$.*

Proof.

$$\Delta R_i(m) = \ln\{P_i(m+1)/P_i(m)\} = \ln\left\{1 + [\lambda_i^{m+1}/(m+1)!]/\sum_{j=0}^{j=m} [\lambda^j/j!]\right\}.$$

It will be sufficient to show that $g(m,\lambda) = [\lambda^{m+1}/(m+1)!]/\sum_{j=0}^{j=m} [\lambda^j/j!]$ is a decreasing function of m for all $\lambda > 0$. Now $g(m,\lambda) - g(m-1,\lambda)$ has the same sign as $f(m,\lambda) = \lambda \sum_{j=0}^{m-1} \lambda^j/j! - (m+1) \sum_{j=0}^{j=m} \lambda^j/j!$. But, after simplification,

$$df(m,\lambda)/d\lambda = f(m-1,\lambda), \qquad (4)$$

with $f(1,\lambda) = -2 - \lambda < 0$ for $\lambda > 0$. Suppose $f(m,\lambda) < 0$ for $m = 1, 2, \cdots, m_0 - 1$. Then $df(m_0,\lambda)/d\lambda < 0$ for $\lambda > 0$ by (4). Since $f(m_0,0) = -(m_0+1) < 0$ and $df(m_0,\lambda)/d\lambda < 0$, then $f(m_0,\lambda) < 0$ for all $\lambda > 0$. By induction, $f(m,\lambda) < 0$ for $m = 1, 2, \cdots; \lambda > 0$. Thus $g(m,\lambda)$ is a decreasing function of m for $\lambda > 0$.

COROLLARY: *$R(n)$ is a concave function of n.*

Proof. $R_i(n_i)$ is a concave function of n_i by Lemma 1. Hence $R(n)=\sum_{i=1}^{i=k} R_i(n_i)$ is concave.

Procedure for Obtaining the Optimal n.

For arbitrary $r>0$, for those i such that $\Delta R_i(0)<rc_i$, define $n_i^*=0$; for the remaining i, define n_i^* as $1+$[largest m such that $\Delta R_i(m)\geqq rc_i$]. Compute $c(n^*)=\sum_{i=1}^{i=k} c_i n_i^*$. The following theorem shows n^* is optimal:

THEOREM 1: *n^* maximizes $R(n)$ among all n such that $c(n)\leqq c(n^*)$ for $n\geqq 0$.*

Proof. We will show for any $0\leqq n\neq n^*$ for which $c(n)\leqq c(n^*)$ that $R(n)\leqq R(n^*)$. Suppose $n_i>n_i^*$ for i in $I_1, n_i<n_i^*$ for i in I_2, where I_1, I_2 are subsets of $\{1,2,\cdots,k\}$. For i in I_1, $\Delta R_i(n_i^*+j)<rc_i$ for $j=1, 2, \cdots, n_i-n_i^*$ since $\Delta R_i(n_i)$ is a decreasing function of n_i by Lemma 1. Thus

$$\Delta R_i(n_i^*+j)<rc_i. \qquad (i \text{ in } I_1;\ j=1,\ 2,\ \cdots,\ n_i-n_i^*) \quad (5)$$

Similarly, for i in I_2,

$$\Delta R_i(n_i^*-j)\geqq rc_i. \qquad (i \text{ in } I_2;\ j=1,\ 2,\ \cdots,\ n_i^*-n_i) \quad (6)$$

Hence

$$\begin{aligned} R(n)-R(n^*) &= \textstyle\sum_{i \text{ in } I_1} \sum_{j=1}^{n_i-n_i^*} \Delta R_i(n_i^*+j) \\ &\quad -\textstyle\sum_{i \text{ in } I_2} \sum_{j=1}^{n_i^*-n_i} \Delta R_i(n_i^*-j) \leqq r \sum_{i \text{ in } I_1} (n_i-n_i^*)\, c_i \\ &\quad -r\textstyle\sum_{i \text{ in } I_2} (n_i^*-n_i)\, c_i = r \sum_{i=1}^{i=k} (n_i-n_i^*)\, c_i = r\{c(n)-c(n^*)\}. \end{aligned}$$

But $r>0$ and $c(n)-c(n^*)\leqq 0$. Hence $R(n)\leqq R(n^*)$.

To obtain a curve showing maximum assurance $P(n^*)$ vs. $c(n^*)$, simply follow the procedure above for an appropriate range of values of $r>0$, computing $P(n^*)$ as well as $c(n^*)$, and plotting the results. *See* Fig. 1 for an example of such an optimal curve.

The actual computation is rapid in the present case of an underlying exponential life distribution. We note that

$$\begin{aligned} \Delta R_i(n_i) &= \ln\left\{1+\frac{\lambda_i^{n_i+1}\exp(-\lambda_i)}{(n_i+1)!} \Big/ \sum_{j=0}^{n_i} \frac{\lambda_i^{\,j}\exp(-\lambda_i)}{j!}\right\} \\ &\approx \frac{\lambda_i^{n_i+1}\exp(-\lambda_i)}{(n_i+1)!}. \end{aligned} \qquad (7)$$

Since the latter expression is tabulated,[12] the computation is simple even with only a desk calculator.

An alternate equivalent method of computing the points on the optimal curve is available; it is more convenient for machine computation. Start-

ing with any point on the optimal curve we may obtain each successive point to the right as follows. Let $(n_1^*, n_2^*, \cdots, n_k^*)$ be the initial optimal point. Then compute $\Delta R_1(n_1^*)/c_1, \cdots, \Delta R_k(n_k^*)/c_k$. If the αth ratio is the largest, the next optimal point to the right of $(n_1^*, \cdots, n_k^*)$ is $(n_1^*, \cdots, n_{\alpha-1}^*, n_\alpha^*+1, n_{\alpha+1}, \cdots, n_k^*)$. Repeat this procedure on the new optimal point. Thus, we may successively obtain as many additional optimal points as we please.

One final point should be noted. Each point n^* on the optimal curve obtained by our procedure has the property that any other kit costing no more provides no greater assurance against shortage. However, there may be other points *not* on the curve having this property. This implies that if a particular cost c_0, not corresponding to any point on the optimal curve, is specified, then it may be possible to obtain a kit composition, n, which satisfies the cost constraint and provides protection against shortage greater than that provided by any point on the optimal curve also satisfying the cost constraint. The loss in protection from using the appropriate point n^* on the optimal curve will be at most the difference in protection provided by n^* and the protection provided by the next point to the right of n^* on the optimal curve. This loss will generally be small, especially for kits having many component types.

ILLUSTRATION

A SYSTEM consisting of a UHF receiving subsystem and a VHF receiving subsystem is to be placed in the field for a three-month period of experimentation. The expensive essential tubes in the two systems are described in Table I.

During the period of operation in the field, the UHF tubes are each scheduled for 332 hours of use and the VHF tubes are each scheduled for 2160 hours of use. Assuming an exponential life distribution for each of the tube types with failure rate as shown above, and assuming independence of operation of the tubes, find an optimal allocation of spare parts for various spares budgets, i.e., an allocation which maximizes assurance of continued system operation during the period in the field.

TABLE I

i	Tube type	Failure rate/hour, μ_i	Cost per tube, c_i	Number in UHF, scheduled for 332 hours of use each, d_{i1}	Number in VHF, scheduled for 2160 hours of use each, d_{i2}	Expected number of failures, λ_i
1	Radechon	1/2500	$240	4	4	4.0
2	Memotron	1/4000	1025	2	5	2.9
3	Carcinotron	1/800	1158	4	0	1.7
4	TWT	1/6000	750	2	0	0.11

First, we compute the expected number of spares of each type used during the period:

$$\lambda_1 = \tfrac{1}{2500}\,\{4\cdot 332+4\cdot 2160\} = 4.0, \qquad \lambda_3 = \tfrac{1}{800}\,\{4\cdot 332\} = 1\cdot 7$$
$$\lambda_2 = \tfrac{1}{4000}\,\{2\cdot 332+5\cdot 2160\} = 2.9, \qquad \lambda_4 = \tfrac{1}{6000}\,\{2\cdot 332\} = 0.11$$

Next, to determine the first value of r to use, compute $\lambda_1+3\sqrt{\lambda_1}$ and round to the nearest integer, obtaining 10. Let $n_1^*=10$. Thus n_1^* corresponds to a value three standard deviations above the mean, since in a Poisson distribution,

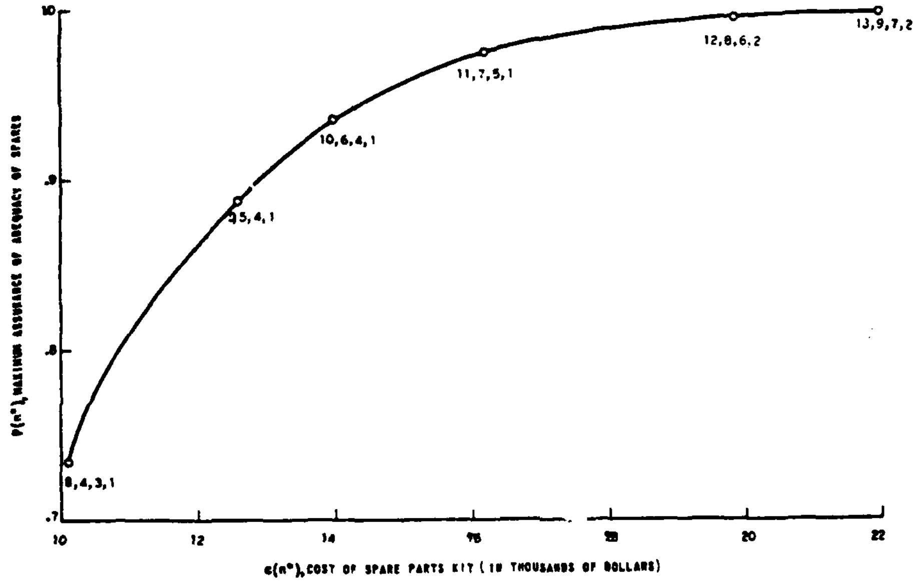

Fig. 1. Optimal spares kits for various budgets.

the standard deviation equals the square root of the mean. Using the approximation (7), we let r be determined from $r=(1/c_1)\exp(-\lambda_1)\,(\lambda_1^{10}/10!)=0.000022$ (Molina's Table I[12]). This initial selection of r thus provides high protection against shortage of component type 1; by the nature of the computation somewhat comparable protection will be provided against shortage of each of the other component types.

We then find n_2^* as the largest value of m such that

$$(1/c_2)\exp(-\lambda_2)\,(\lambda_2^{m}/m!) \geqq 0.000022. \tag{8}$$

Using Molina's Table I,[12] we find $n_2^*=6$.

Replacing the subscript 2 in (8) by 3 and 4 respectively and proceeding similarly, we find $n_3^*=4$ and $n_4^*=1$.

From $n^* = 10, 6, 4, 1$, we compute

$$P(n^*) = \prod_{i=1}^{i=4} \sum_{x=0}^{x=n_i^*} \exp(-\lambda_i)(\lambda_i^x/x!) = 0.935,$$
$$c(n^*) = \sum_{i=1}^{i=4} c_i n_i^* = \$13{,}932.$$

Thus to obtain maximum assurance of continued system operation under a budget of \$13,932 for spares of the four tube types, we would stock 10 radechons, 6 memotrons, 4 carcinotrons, and 1 TWT. The assurance obtained would be 0.935.

By taking $n_1^* = 8$, 9, 11, 12, and 13 respectively, and proceeding in a similar fashion, we would obtain the other five points plotted in Fig. 1. (A smooth curve is shown for simplicity, although, because of the discrete nature of the variables, a step function is actually correct.) Thus Fig. 1 shows the maximum assurance of continued system operation obtainable for a given budget for spares. In addition, the composition of the spares kit yielding the plotted maximum assurance is shown next to each point. Note that additional points lying between those shown on the optimal curve of Fig. 1 may be computed if desired.

MORE GENERAL LIFE DISTRIBUTIONS

THE RESULTS obtained thus far are based on the assumption that component failures follow exponential distributions. Can we obtain a solution in the case of nonexponential life distributions?

The answer is yes. If we examine Theorem 1 carefully to see wherein we used the fact that our underlying life distribution is exponential, we see that this fact implies that $\Delta R_i(n_i)$ is a decreasing function of n_i, a condition needed to prove the theorem. Thus to apply our procedure (appearing just before Theorem 1) for obtaining the optimal n in the case of nonexponential life distributions we need only ensure that $\Delta R_i(n_i)$ (defined as $\ln[P_i(n_i+1)/P_i(n_i)]$, where $P_i(n_i)$ is the probability that at most n_i spares of the ith type are used) be a decreasing function of n_i.

It turns out that $\Delta R_i(n_i)$ is a decreasing function of n_i when the underlying densities $f_i(t)$ for the time of failure of components of the ith type, $i=1, 2, \cdots, k$, have the property (*monotone likelihood ratio* property in differences):

$$f_i(t_1-\omega_1)/f_i(t_1-\omega_2) \geq f_i(t_2-\omega_1)/f_i(t_2-\omega_2) \tag{9}$$

whenever $t_1 < t_2$ and $\omega_1 < \omega_2$. (If either denominator is 0, use $f_i(t_1-\omega_1)$ $f_i(t_2-\omega_2) \geq f_i(t_1-\omega_2)\, f_i(t_2-\omega_1)$. This property characterizes (a) the exponential distribution, (b) the Gamma distribution, (c) the normal distribution, and many other distributions. (*See* KARLIN,[7, 8, 9, 10] and SCHOENBERG[14] for a full discussion of this class of distributions and their applications in statistical decision theory.)

Thus, if each failure density $f_i(t)$ has the monotone likelihood property of (9), the optimal spares kit may be obtained using the procedure de-

scribed just before Theorem 1. In addition, the optimality results of Theorem 1 hold. The proof is not given in this paper, but is contained in PROSCHAN[13] and will appear in the near future in one of the statistical journals.

The computation involved is considerably more tedious since, in general, the distribution for the number of failures experienced (Poisson in the case of the exponential life distribution) for any component type is no longer obtainable in closed form, but only by detailed computation.

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SPARE PART KITS AT MINIMUM COST*

Guy Black and Frank Proschan
Sylvania Electronic Defense Laboratory
Mountain View, California

I. GENERAL STATEMENT

1. The Problem

In the military establishment it is not always practical to rely on the existing system of supply depots for the spare parts needed to maintain electronic equipment. For example, military agencies are continually testing new equipment, of which only one or a few are built. The components used may not always exist in supply channels, which in any case are not geared to meet the requirements of such equipment. For these reasons the supplier of the experimental equipment may be asked to provide spare parts in sufficient quantity to carry the equipment through the evaluation program.

The contractor who receives such a request has difficulty in deciding how many spares as well as just which ones to supply, and how to budget for spares. He can rely on a few rules of thumb that have grown up in supply agencies, but these have not been particularly successful. Further, there are no standards by which performance in selecting spares can be judged. The root of the problem is that spare parts consumption is a random process. Statistical records on electronic component failure indicate that often the rate of failure is quite constant during a large part of equipment life, meaning that an exponentially declining probability density function must be used to describe the probability that a component will survive a given number of hours.

The problems encountered with rough and ready methods are illustrated by Figures 1 and 2. Figure 1, from Davis,[1] is a typical failure curve, with a mean time to failure of 179 hours. It would be naive to assume that two V605 tubes would be adequate for 358 hours, given this distribution yet, this kind of assumption has been made. If, on the other hand, the distribution were of the type shown in Figure 2, the assumption would not be too unreasonable as a rough approximation.

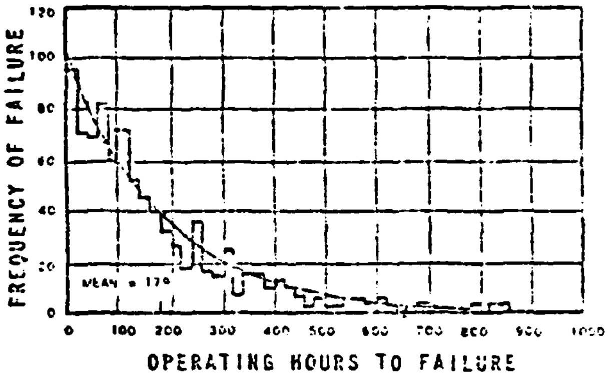

Figure 1

Distribution of Failure Frequency with Operation Time -- Type V605 Vacuum Tube Used in Transmitter

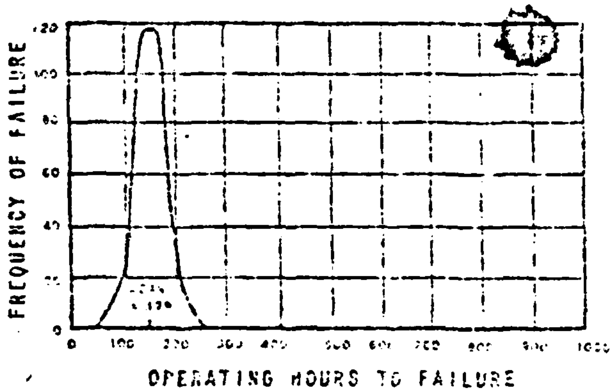

Figure 2

Hypothetical Distribution of Failure Frequency with Operating Time

The commonness with which distributions of the type of Figure 1 occur, or which are normal with extreme variance, makes it highly desirable to use a more scientific approach to determine spare parts requirements. A policy problem is also illustrated by these curves, which must be resolved before a solution can be reached. Since parts fail in a probabilistic manner there is never an absolute certainty that a quantity of spares, no matter how large, is adequate. It makes no sense to demand

* Prepared under Signal Corps Contract DA-36-039-SC-75012.

certainty that spares provided will be adequate; what must be done is to specify the order of probability of adequacy that is required. The probability may be as close to unity as desired, but high probability can be obtained only at considerable cost.

The object of this paper is to indicate an approach to spare parts policy and the means of implementing it. To accommodate both the general and the mathematical reader, the paper is divided into three parts. Part I covers the subject in a general way, with minimum mathematics. It may be read separately, and is an introduction to Part II. Part II derives a mathematical statement of spare parts requirement where failure rates are exponential, solves the mathematical problem of optimization, and gives a concrete example. Part III is a non-mathematical evaluation of the approach outlined, including indications of how it might be extended, and the policy implications for military spare parts procurement. This part is of general interest.

2. Probabilistic Interpretation of Spare Requirements

2.1 General.

To determine the number of spares required for any assurance of adequacy what is needed is a distribution that describes probability of failure of a component, the time period for which spares are to be provided, and the acceptable probability of adequacy. As shown in Part II the probability of adequacy as a function of number of spares is a Poisson distribution, when the failure distribution is exponential. The wide use of the exponential failure distribution in the reliability literature gives this formulation special importance, and it is particularly easy to work with. Even where the distribution is not exponential probability of adequacy can be determined, as is illustrated below.

2.2 Example.

Assume the following:

(a) There is an original part and one spare to be used sequentially.

(b) The same probability distribution applies to the original and the spare. The probability of failure of the part is 0.1 at hour 0, 0.3 at hour 1, 0.4 at hour 2 and 0.2 at hour 3. For simplicity, failure at other times is assumed not to occur.

(c) The spare is adequate if the sum of lifetimes actually experienced by the original and the spare exceeds the required time of operation.

Assume one spare is on hand. The problem is to find the probability distribution that either the original or the spare will be operable at 0, 1, 2, etc. hours.

Table I gives all possible outcomes. For example, there is a 0.2 probability that the original will last exactly three hours, and a 0.3 probability that the spare will last one hour. Thus, there is a 0.06 probability attached to the three-one entry in the table. All other box entries can be calculated in the same way.

Table I

Probability of Component and Spare Failing at Certain Times

Hour of Failure of Spare	Hour of Failure of Original			
	0	1	2	3
0	0.01	0.03	0.04	0.02
1	0.03	0.09	0.12	0.06
2	0.04	0.12	0.16	0.08
3	0.02	0.06	0.08	0.04

Next, consider the ways in which failure at a certain exact number of hours can occur. If four hours is taken as an example, three hours for the original plus one hour for the spare will satisfy the requirement, as does the 1-original 3-spare case and the 2-original 2-spare case. The probability of failing at exactly four hours is $0.06 + 0.06 + 0.16 = 0.28$

Similarly, the probability of operating at least four hours can be calculated. In Table II, the results for all possible times are presented. The result is a probability distribution which relates time to assurance of adequacy.

The last column of Table II gives the probability of not running out where there are no spares. The difference between the last two columns gives the increment of assurance purchased by adding a spare. Note that additional assurance of availability is gained by a spare regardless of the number of hours of operation. This comparison could be extended for two or

Table II

Probability of Adequacy for a Kit Composed of a Single Spare for Specified Periods of Time

Hrs. (H)	Possible ways of achieving adequacy	Pr. of running out of spares at exactly H	Pr. of running out not later than H	Pr. of not running out by H	Pr. of not running out by H if no spare is provided
0	0, 0	0.01	0.01	0.99	0.9
1	1, 0; 0, 1	0.06	0.07	0.93	0.6
2	2, 0; 0, 2; 1, 1	0.17	0.24	0.76	0.2
3	3, 0; 0, 3 2, 1; 1, 2	0.28	0.52	0.48	0.0
4	3, 1; 1, 3, 2, 2	0.28	0.80	0.20	0.0
5	3, 2; 2, 3	0.16	0.96	0.04	0.0
6	3, 3	0.04	1.00	0.00	0.0

more spares, but the mathematics would be tedious without an electronic computer. With the exponential failure distribution, the result can be obtained directly from the number of spares, using tables of the Poisson distribution.

3. Optimization of Design of a Spare Parts Kit

The probability of adequacy of spares can be increased, with unity the unattainable limit, by increasing the number of spares. However, high orders of assurance are expensive, because with almost any component failure distribution or equipment design, the increased adequacy achievable with an additional spare becomes very small as the number of spares becomes large. Determining the number of spares for a single component, given the failure rate, is merely a matter of specifying an acceptable probability of adequacy on the basis of operational considerations and cost.

Where a spare parts kit provides for many different components, failure of any one of which renders an equipment inoperative, the problem is more complex. The objective of selecting spares is a certain assurance that the equipment will not become inoperative due to shortage of spares. In a simple series system this equipment assurance is the product of the assurances for each part. The essential difference is that in the multiple-component kit there are many possible combinations of spares that will meet any specified assurance of adequacy.

An example may be in order: If, for a system composed of two "black boxes", an assurance of 0.5 is desired for a kit of spares, any combination of assurances for individual black boxes, the product of which exceeds 0.5, will meet the requirement. One spare for A may mean an assurance of 0.7 that there will be an operating "A" unit available. One spare for B may mean 0.6, two spares 0.8, three spares 0.9, four spares 0.95, etc. To meet the 0.5 criteria, at least two spares for B appear to be needed. Note, however, that conceivably the spare A could be dropped, and the criterion still met by increasing the numbers of spare B's.

Because of these relationships, some additional criterion must be used to choose among possible kits. Minimization of initial purchase cost is generally quite important, and will be used as the additional criterion for illustration. Cost is easily determined from the quantities and unit prices of spares, and with this information the cost of a kit can be determined. Many other criteria are possible, for example: least weight or volume; minimum delay in availability; likelihood of deterioration in storage; total cost, including acquisition, storage and transportation costs; an index reflecting a combination of desirable qualities.

4. Theoretical Basis for Selection

Fortunately, it is not necessary to price out every possible kit of spares to determine

will have least cost for any assurance ...ity. A simple rule is available to ...ima, derived from the marginal ...miliar in economics.[2] This rule has ...age of pointing a way to a simple comp- ...pproach so that determination of the ...t of spares requires no more than a ...puter.

...amental in this rule is the idea that ...ing spares, it is possible to buy assur- ...vailability. The assurance for an ... of spares both for n spare units of A, ... spare units is calculated. A ratio of the ...nt of assurance $(P_{(n+1)} - P_n)$ over the ... a spare A may be called the "marginal ...nce" due to the n + 1st spare of A. Under ... reasonable assumptions, marginal assur- ... is a declining function of the number of ... A's as shown in Figure 3, approaching the ... asymptotically.

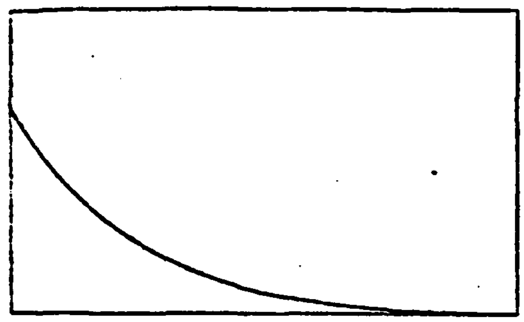

Figure 3

Marginal Assurance as a Function of Number of Spares

At an optimum, these marginal assur- ... must be equal for all parts for which any ... are provided at all (within limits imposed ... that individual spares are not divisi- ... components for which it is impossible ... this value of marginal assurance, no spares are provided at all. Similar proposi- tions have been used in economics: the theory of production contains interesting parallels.[3]

An intuitive proof may be stated briefly as follows: Suppose we omit a spare of type A, reducing assurance of the entire kit by ΔP_a, and reducing expenditure by ΔC_a, where C_a is the cost of a spare of type A. (The value of P_a depends on numbers of spare B's, C's, etc.) If it were possible to buy spares of B, C, etc., with the sum of money, ΔC_a in such quantity that the assurance was increased by more than ΔP_a, the kit (before the change) was not optimum. This is so because a better one could be found for the same money. If no improvement were pos- sible, the kit was optimum. Thus a condition of optimality is that for all parts for which any spares are provided at all,

$$r = \frac{\Delta P_a}{\Delta C_a} = \frac{\Delta P_b}{\Delta C_b} = \frac{\Delta P_c}{\Delta C_c} = \ldots$$

For any value of r there is a corresponding assurance for the entire kit; the level of assur- ance and r are functionally related. As will be shown in Part II, by working with logarithms of probabilities the optimum can be found quite easily.

The computational method is based on a comparison of marginal assurances for spares. In general, to select a value of kit probability, and derive from it the corresponding value of r requires excessive computation since parameters associated with every type of spare enter into the relationship. It is more practicable to select a value of r arbitrarily and work out an optimum kit for some assurance not known in advance. Given the basic parameters -- failure rates, numbers of components, their prices and number of operating hours required -- computation is very simple with available tabulations of the Poisson distribution. If a certain kit assurance is desired, the proper value of r can be deter- mined by a number of successive calculations.

II. MATHEMATICAL STATEMENT

5. Mathematical Solution of Problem

5.1 Mathematical Statement of Problem.

The problem is to determine the number of spare parts of each type required to give any specified assurance of continued operation of a complex system during a given period, at minimum cost for spares.

Specifically, the equipment is to function t_o hours. During that period each of d_{ij} essential components of type i will receive t_j hours of use, $j = 1,2, \cdots, m_i$, $i = 1,2, \cdots, k$. A single unit of type i costing c_i dollars has an exponential life distribution with failure rate per hour of μ_i, $i = 1,2, \cdots, k$. Independence of component failures is assumed. If n_i spares are initially provided for type i, the total cost of spares is

$$c = \sum_{i=1}^{k} c_i n_i$$

No replenishment of the spare parts supply is possible after the placement of the equipment in the field. What choice of $(n) = (n_1, n_2, \cdots, n_k)$ will yield assurance $\geq \alpha$ of system survival at minimum cost c?

5.2 Derivation.

First we show that the number of spares of component type i consumed during the t_o hours is a Poisson random variable with parameter

$$\lambda_i = \mu_i \sum_{j=1}^{m_i} d_{ij} t_j .$$

Several lemmas are needed:

Lemma A.

If d components having the common life density $\mu e^{-\mu x}$ are operating simultaneously, then Y, the time of the first failure has a density of $d\mu e^{-d\mu x}$

Proof

$$P\left[Y \geq t \right] = \left\{ \int_t^\infty \mu e^{-\mu x} dx \right\}^d = e^{-d\mu t} .$$

Hence the density of Y is $d\mu e^{-d\mu x}$.

Lemma B.

If X_i, $i = 1, \cdots, n$, are independent random variables with density $f_X(x) = \mu e^{-\mu x}$, $x \geq 0$ then $S = \sum_{i=1}^{n} X_i$ has density

$$f_S(s) = \frac{\mu^n s^{n-1}}{(n-1)!} e^{-\mu s}, \quad s \geq 0. \tag{1}$$

Proof

Let $\phi_i(t)$ be the characteristic function of X_i. Then

$$\phi_i(t) = \int_0^\infty e^{ixt} \mu e^{-\mu x} dx = \frac{\mu}{\mu - it}$$

Hence $\phi_s(t) = \dfrac{\mu^n}{(\mu - it)^n}$, the characteristic function of (1). Q.E.D.

Designate those units of type i required to survive t_{ij} hours as being of subtype i, j. The probability that the number K_{ij} of subtype i, j consumed during the t_j hours of use $\leq n_{ij}$ is, b Lemma A and Lemma B:

$$\int_{t_j}^\infty \frac{(d_{ij}\mu_i)^{n_{ij}}}{n_{ij}!} e^{-d_{ij}\mu_i s} ds$$

$$= \sum_{x=0}^{n_{ij}} (1/x!)(d_{ij}\mu_i t_j)^x e^{-d_{ij}\mu_i t_j} \tag{2}$$

(See Mood[4], for the justification of the last equation.) Thus we have

Lemma C.

N_{ij} is a Poisson variate with parameter $d_{ij}\mu_i t_j$.

Next note that

$$N_i = \sum_{j=1}^{n_i} N_{ij} \tag{3}$$

where n_i is the number of spares needed for type i. Then it follows that:

Theorem A

N_i is a Poisson variate with parameter

$$\lambda_i = \mu_i \sum_{j=1}^{n_i} d_{ij} t_j \ .$$

The probability $P(n)$ of system survival is

$$P(n) = f\left[P_i(n_i) \right] .$$

The nature of the function f is dictated by the manner in which equipment operation is affected by failure of any of the parts. If all parts must operate for the equipment to operate, and all parts are independent,

$$P(n) = \prod_{i=1}^{k} P_i(n_i) \tag{4}$$

where

$$P_i(n_i) = \sum_{z=0}^{n_i} (\lambda_i^z / z!) e^{-\lambda_i} \tag{5}$$

We will need

Lemma D.

$$g(n,\lambda) = \lambda^{n+1}/(n+1)! \Big/ \sum_{j=0}^{n} \lambda^j/j!$$

is a strictly decreasing function of n for all $\lambda > 0$.

Proof. Consider $g(n,\lambda) - g(n-1,\lambda) =$

$$\left\{ [\lambda^{n+1}/(n+1)!] \sum_{j=0}^{n-1} (\lambda^j/j!) - (\lambda^n/n!) \sum_{j=1}^{n} (\lambda^j/j!) \right\} \Big/ \sum_{j=0}^{n} (\lambda^j/j!) \sum_{j=0}^{n-1} (\lambda^j/j!)$$

Thus $g(n,\lambda) - g(n-1,\lambda)$ has the same sign as

$$f(n,\lambda) = \lambda \sum_{j=0}^{n-1} (\lambda^j/j)! - (n+1) \sum_{j=0}^{n} (\lambda^j/j!) \ .$$

Next note that

$$\frac{df(n,\lambda)}{d\lambda} = \sum_{j=0}^{n-1} (\lambda^j/j!) + \lambda \sum_{j=0}^{n-2} (\lambda^j/j!) - (n+1) \sum_{j=0}^{n-1} (\lambda^j/j!) = \lambda \sum_{j=0}^{n-2} (\lambda^j/j!) - n \sum_{j=0}^{n-1} (\lambda^j/j!) = f(n-1,\lambda) \ .$$

Now $f(1,\lambda) = \lambda - 2(1+\lambda) = -2 - \lambda < 0$ for $\lambda > 0$.
Also if we assume

$f(n,\lambda) < 0$ for $n = 1, 2, \cdots, n_o - 1$,

then

$$\frac{df(n_o,\lambda)}{d\lambda} < 0$$

for $\lambda > 0$.

$f(n_o, 0) = -(n_o + 1) < 0$.

Thus

$f(n_o,\lambda) < 0$ for all $\lambda > 0$.

Thus, by induction,

$f(n,\lambda) < 0$ for $n = 1, 2, \cdots; \lambda > 0$.

Hence

$g(n,\lambda) - g(n-1,\lambda) < 0$ so that $g(n,\lambda)$ is a strictly decreasing function of n for $n \geq 1$, $\lambda > 0$. Q.E.D.

Next we obtain the optimal set $(n_1, \cdots, n_k)$.

We wish to minimize C for $n_i \geq 0$, $i = 1, 2, \cdots$, and $P(n) \geq \alpha$.

Equivalently, we want to minimize C for $n_i \geq 0$, $i = 1,2, \cdots, k$, subject to $R = \log P \geq \beta = \log \alpha$ (since $\log P$ is a monotonic function of P). Define $R_i = \log P_i$. Then

$$R = \sum_{i=1}^{k} R_i$$

Also define

$$\Delta R_i(n_i) = R_i(n_i + 1) - R_i(n_i) \cdot \tag{6}$$

<u>Lemma F.</u>

$\dfrac{\Delta R_i}{c_i}$ is a strictly decreasing function of n_i.

This follows immediately from Lemma D since $\log(1 + u)$ is a strictly increasing function of u.

<u>Procedure for Obtaining Optimal (n).</u>

To obtain the minimum cost function of a family of system reliabilities along with the corresponding optimal (n), we proceed as follows: We pick a value $r > 0$. For those i such that

$$\frac{\Delta R_i(0)}{c_i} < r$$

we set $n_i^* = 0$; for the remaining i, we set n_i^* = largest n_i such that

$$\frac{\Delta R_i(n_i)}{c_i} \geq r \tag{7}$$

Next compute $P(n^*) = \alpha(r)$, say. The following theorem shows (n^*) is optimal.

<u>Theorem F.</u>

(n^*) minimizes $C(n)$ among sets (n) for which $P(n) \geq \alpha(r)$.

<u>Proof</u>

We will show that for any $(n) \neq (n^*)$ with $P(n) \geq \alpha(r)$, then $C(n) > C(n^*)$.

Suppose $n_i > n_i^*$ for i in I_1, $n_i < n_i^*$ for i in I_2, where I_1, I_2 are subsets of $\{1,2, \cdots, k\}$. For i in I_1,

$$\frac{\Delta R_i(n_i^* + j)}{c_i} < r \text{ for } j = 1,2, \cdots, n_i - n_i^*$$

since

$$\frac{\Delta R_i(n_i)}{c_i}$$

is a decreasing function of (n_i). Thus

$$\Delta R_i(n_i^* + j) < rc_i ;$$
$$\text{for } i \text{ in } I_1,\ j = 1,2, \cdots, n_i - n_i^* \tag{8}$$

Similarly, for i in I_2,

$$\Delta R_i(n_i^* - j) > rc_i$$

$$\text{for } i \text{ in } I_2,\ j = 1,2, \cdots, n_i^* - n_i. \tag{9}$$

Hence

$$\sum_{i \in I_1} \sum_{j=1}^{n_i - n_i^*} \Delta R_i(n_i^* + j)$$

$$- \sum_{i \in I_2} \sum_{j=1}^{n_i^* - n_i} \Delta R_i(n_i^* - j) < r \sum_{i \in I_1} (n_i - n_i^*) c_i$$

$$- r \sum_{i \in I_2} (n_i^* - n_i) c_i = r \sum_{i \in I_1, I_2} (n_i - n_i^*) c_i$$

Thus

$$0 \leq R(n) - R(n^*) = \sum_{i \in I_1} \sum_{j=1}^{n_i - n_i^*} \Delta R_i(n_i^* + j)$$

$$- \sum_{i \in I_1} \sum_{j=1}^{n_i^* - n_i} \Delta R_i(n_i^* - j) < r \sum_{i \in I_1, I_2} (n_i - n_i^*) c_i$$

$$= r \left\{ \sum_{i=1}^{k} n_i c_i - \sum_{i=1}^{k} n_i^* c_i \right\} = r \left\{ C(n) - C(n^*) \right\}$$

Since

$r > 0,\ c(n) > c(n^*)$. Q.E.D.

Now repeat the above procedure for a range of values of r. In each case, compute $c(n^*)$ and plot it as a function of $\alpha(r)$. The resulting curv represents minimum spare parts cost as a function of assurance of adequacy of the spare part kit.

5.3 Computation.

The computation is rapid since the required Poisson probabilities are tabulated. An approximation which may be used to speed the calculation is

$$\Delta R_i(n) \sim \left[\lambda_i^{n+1}/(n+1)!\right] e^{-\lambda_i} \Big/ P_i(n)$$

$$\sim \left[\lambda_i^{n+1}/(n+1)!\right] e^{-\lambda_i} \qquad (10)$$

The latter expression is tabulated by Molina[5].

As k increases, the amount of computation increases in a strictly linear fashion. Thus for any actual system involving hundreds of essential components, a desk calculating machine computation is feasible to generate $n^*(\alpha)$, and

$c(n^*)$ for a range of α's.

5.4 Example.

Consider the following problem by way of illustration. A UHF receiving system and a VHF receiving system are to be placed in the field. The expensive essential tubes in the two systems are described in Table III.

During the period of operation in the field, the UHF tubes are scheduled for $t_1 = 2000$ hours of use and the VHF tubes are scheduled for $t_2 = 13000$ hours. Assuming an exponential life distribution for each of the tube types with failure rate as shown above, and assuming independence of operation of the tubes, find an optimum allocation of spare parts for various levels of assurance that the system will not run out of spare parts of the four tube types.

First compute the expected number of spares of each type used during the period

$$\lambda_1 = 1/2500(4\cdot 2000 + 4\cdot 13000) = 24$$

$$\lambda_2 = 1/4000(2\cdot 2000 + 5\cdot 13000) = 17.25$$

$$\lambda_3 = (1/800)4\cdot 2000 = 10$$

$$\lambda_4 = (1/6000)2\cdot 2000 = 0.67$$

Next somewhat arbitrarily select $n_1^* = 34$. Let

$$\beta_1(x) = e^{-\lambda_1}\lambda_1^x/x!$$

This determines a value for

$$r = \frac{1}{c_1}\log\frac{\sum_{x=0}^{n_1^*+1}\beta_1(x)}{\sum_{x=0}^{n_1^*}\beta_1(x)} = 1.37\times 10^{-5}$$

With

$$\beta_1(x) = e^{-\lambda_1}\lambda_1^x/x!$$

TABLE III

i	Tube Type	μ_i, Failure Rate Per Hour	c_i, Cost Per Tube ($)	d_{i1}, Number In UHF	d_{i2}, Number In VHF
1	Radechon	1/2500	240	4	4
2	Memotron	1/4000	1025	2	5
3	Carcinotron	1/800	1158	4	0
4	TWT	1/6000	750	2	0

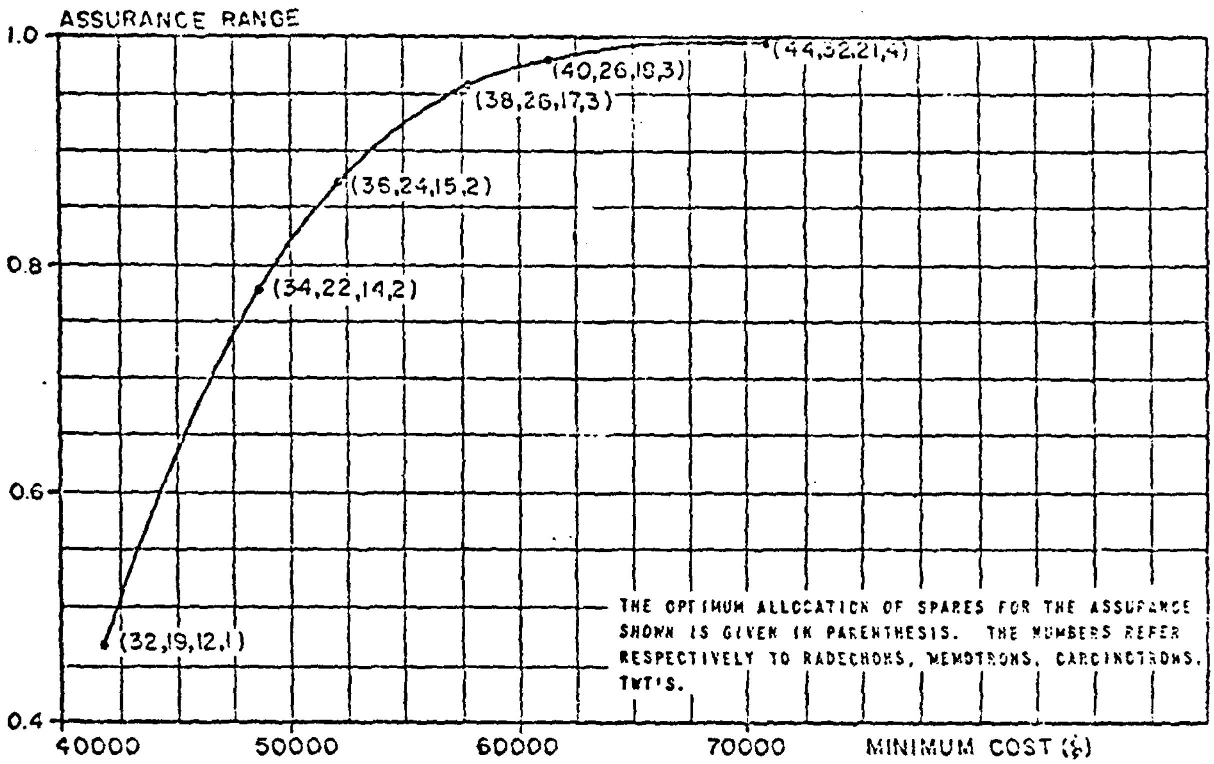

Figure 4

Assurance versus Minimum Cost

we then find n_2^*, the largest value of n_2 such that

$$\frac{1}{c_2}\log\frac{\sum_{x=0}^{n_2+1}\beta_2(x)}{\sum_{x=0}^{n_2}\beta_2(x)} \geq 1.37\times10^{-5} .$$

$n_2^* = 22$. Similarly $n_3^* = 14$ and $n_4^* = 2$.

From n_1^*, n_2^*, n_3^*, n_4^*, we compute

$$P(n^*) = \prod_{i=1}^{4}\sum_{x=0}^{n_i^*} e^{-\lambda_i}\lambda_i^{x}/x! = 0.78$$

and

$$c(n^*) = \sum_{i=1}^{4} c_i n_i^* = \$61,450$$

Thus to attain 0.78 assurance at minimum cost of having sufficient spares we should stock 34 radechons, 22 memotrons, 14 Carcinotrons, and two TWT's. The cost of spares is $61,450.

By taking $n_1^* = 32, 36, 38, 40, 44$ and proceeding in a similar fashion, the other points plotted in Figure 4 can be obtained.

This curve shows the relationship between assurance of adequacy of spares and cost of an optimum kit. Once a few points have been calculated, it is possible to interpolate, and estimate the value of r corresponding to a specified level of assurance. Thus, by one additional calculation, the optimum kit for any specified level of assurance can be determined.

III. APPLICATION OF ANALYTICAL RESULTS

6. Application

A straightforward approach is available, by means of which an optimum spare parts kit can be selected, given basic data and a sufficient statement of the problem. The approach, which is related to the marginal analysis familiar in economics, is mathematically valid, can be handled computationally by desk calculators and available tables of Poisson distribution, and yields results of practical consequence.

It will not escape attention of those familiar with operations research literature that the spare parts problem is an inventory problem.[6] This raises the question of how this model fits into the general framework of inventory theory.

In answering the question, it is well to recognize two distinct parts of the model. The first part deals with the mechanism by which demand for spares is created. Because failure rates for electronic parts are predictable, means do exist for a priori prediction of demand; most inventory models take demand functions as given.

Given a demand function based on a probabilistic statement of spares requirements, the remainder of the model is simple, involving a single supply period. No attention has been paid to storage cost or reorder cost, and instead of a penalty function for shortage, a permissible probability of shortage has been stated.

The demand function can be changed without changing the method of optimization. For example, an exponential failure distribution need not be used, although, as most available failure data are based on it, usually it will be a reasonable assumption. Also, exponential failure distributions permit use of the very convenient Poisson distribution. If computers are available, use of a more complex failure curve, perhaps reflecting a high failure rate for the break-in period, a long period of constant failure, and a "normal" portion centered around the wearout period, would be practical. While such approaches represent meaningful refinement, the scientific validity of the exponential distribution should not be overlooked.[7]

The second part of the model relates to the objective function optimized. In the present model, assurance of adequacy of the kit has been maximized. In other treatments, different objective functions have been optimized. For example, Karr and Geisler[8,9,10] and Gourary[11,12] optimize (minimize) expected "weighted shortage".

An appealing feature of the model and method of optimization is that it is usable without any particular training, with widely available tools. There are no insurmountable difficulties in extending the method to larger systems involving hundreds of types of parts. The amount of calculation is not as formidable as appears. The same basic calculations can be used over and over again, in the same system and in different systems, if a marginal approach is used. This point may be further explained: while there are many individual parts in electronic systems, they fall into a much smaller number of classes. Often all parts of one class (deposited carbon resistors, for example) will have the same failure rate, the same unit price and the incremental values of log assurance divided by unit price will be the same. Thus, one set of calculations will do for the entire class. For systems using up to approximately 200 classes of parts, Molina's table is satisfactory.

Crucial in application of the method described is the availability of adequate data on component failure rates. RCA[13] and Vitro[14] data can be used. Fortunately, because component failure data are needed in estimates of system reliability, a great deal of effort is going into their collection. The quantity and quality are steadily improving. Their use in estimating spare parts requirements represents a further use, and an additional justification for instituting a well-conceived field reliability program of collecting failure rate data.

7. Implications for Spare Parts Policy

Recommendations for procurement policy for spare parts for experimental equipment are suggested by the analysis in this paper. The probabilistic nature of component failures should be recognized in specifications and some probability -- less than unity -- should be explicitly stated as the objective for selection of spares. The buyer of spares should specify ground rules such as period of operation, and some agreement must be made, based on manner of operation, on the component failure rates to use.

A change in the manner of procuring spares should also be considered. No equipment contractor can determine the total budget for spares until ground rules are established, or until the component composition of the equipment is determined. With developmental equipment, this

information is not normally available until the program is well under way. A contractor who guesses at spares requirements without thorough preliminary analysis, is extending himself considerably. He can either budget a certain sum for spares -- perhaps using the familiar rule of 10 per cent of the cost of material -- or if it is possible to postpone determination of the cost of the kit, he can agree to supply an optimum kit for a specified level of adequacy. Development contracts requiring spares might indicate one of these alternatives.

A better approach would be to require the contractor to calculate the relationship between cost of optimum spare parts kits and probability of adequacy. These calculations would follow the procedure outlined in this paper, and the results would be a cost-assurance curve. From the results, decision as to that point on the curve representing the best balance between cost and adequacy could be made, and a contract for spares negotiated.

Although not fully discussed in the body of the paper it appears from inventory theory that the restriction of spare parts supply to one stocking period will sometimes be inferior to a multiple stocking program. If spares are initially supplied for a portion of the period of operation, and an inventory of remaining spares is taken toward the end of the portion of the period -- this being the basis for reordering for the next period -- fewer spares must be bought to maintain continuously a given probability of adequacy throughout the life of the equipment. Under a multiple plan, a contractor would supply spares for a limited period, records would be kept of use of spares, which would be replenished at regular intervals. An analytical determination of an optimum plan probably would be the contractor's responsibility, and he would be expected to determine the optimum reorder period, make corrections in failure rates based on field experience.

In summary, the whole matter of spare parts policy is worth an analytical treatment, and analysis can result in significant improvement. Procurement contracts for spares should be based on such an analysis. As part of a development effort, contractors should be requested to submit spare parts plans for several alternative levels of assurance of adequacy. Since the analysis is not possible until the form of the equipment is fairly well established, it would be advantageous to procure the bulk of spares upon conclusion of the development effort. The use of the general approach to spare parts problems, using component failure rates, parts population of a system, and a specified probability of adequacy as one criterion, the other being minimized cost or some other quality has much to recommend it.

The merit of a cost-assurance curve as a guide for policy should not be overlooked. A rational decision as to the level of assurance desired in a kit cannot be made without some reference to cost, and for a purchaser of spares to pick arbitrarily some such figure as 0.95 is to shoot in the dark unnecessarily. It is feasible to make cost and assurance estimates for a number of values of assurance, and to determine graphically a function relating assurance and cost as was done in Figure 4. Since the factors influencing selection of a given assurance involve many factors not readily amenable to analysis, there is much to recommend postponing selection of the value of assurance until such a curve can be constructed.

8. Appendix -- Calculation of a Spare Parts Kit

This appendix gives details of a step-by-step procedure for calculation of an essential spare parts kit. This procedure can be followed by a statistical clerk without reference to the body of the report. A desk calculator and a copy of Molina's "Poisson s Exponential Bionmial Limit" are the only necessary tools.

As a practical matter certain parts may be omitted from optimization because of limitations imposed by Molina's table, or available data, because an exponential failure rate cannot be assumed, or because, in engineering judgment, these parts are not vital for reliable operation.

Computation Procedure.

Establish Requirements. With user of spares agree on:

(a) Period of time for which he desires to be supplied with spares, and hours of operation intended for each piece of equipment.

(b) Whether he requires:
Maximum assurance (P_s) for a stated cost;
Specified assurance at a minimum cost;
A cost-assurance curve.

Establish Parts Population. Prepare a consolidated parts list including all components in all equipment to be maintained with a given group of spares. List all

parts, but circle in red parts that according to engineering judgment are not essential for reliability and omit them from all calculation. (They may be supplied on some other basis.) Determine prices of each type of spare.

Establish Failure Rates. Determine mean time between failures from agreed on sources. Base on intensity of application where pertinent.

Record Information. Enter information from the first three steps in columns 1 to 11 of a computation sheet similar to Figure 5, following the instructions below:

Column (1) Sequential numbering of the items.

(2) and (3) Short description, as necessary to identify.

Column (4) If MTBF of parts depends on intensity of use, record symbol identifying intensity in (4). For a given component make separate entries for each differing MTBF.

(5) 1 ÷ MTBF in hours, which is the failure rate appropriate for intensity of application noted in (4).

(6) Hours of anticipated use.

(7) Quantity in use in all equipment, grouped according to entries in (5) and (6).

(8) For all a component with the same MTBF multiply 5 by 6 and the result by 7.

(9) All of the entries in (8) for a particular component should be added and entered in (9). The result is the expected number of failures.

(10) Leave blank (temporarily).

(11) Cost per unit, in dollars.

Preliminary Editing. At this time determine what section of the essential spares kit is to be optimized. Available tables will limit computation to several hundred items, so that for very large kits it is not possible to include all items. Using the value of expected number of failures in (9) multiplied by unit cost (11) as an indication of importance, make a selection omitting components for which the product is below some value. Indicate items omitted by circling in red pencil the entry in (9). Enter in (10) the value appearing in available tables of the Poisson which is closest to the non-circled entries in (9).

Calculation of a Trial Value of r. Count k, the number of part types for which spares are to be optimized, which should equal the number of entries in (10). The manner of determining a trial r is as follows: Select a spare of importance for which the expected number of failures times cost falls somewhere in the middle range of such products. Calculate the kth root of the assurance (P_s) desired for the kit, as established in the first step. Next, determine the number of spares, n, necessary for an assurance for the selected part equal to $P_s^{1/k}$. Use a table of logarithms. Using Molina, Table II, determine for this value of n

$$P_s = 1 - \sum_{x=n+1}^{\infty} \frac{e^{-\lambda}\lambda^x}{x}$$

(Note: In Molina c is used instead of n, and a instead of λ.) Then determine the corresponding value of r, which may be closely approximated by:

$$r = \frac{e^{-\lambda}\lambda^{n+1}}{(n+1)} \cdot \frac{1}{C}$$

using Molina, Table I, for the Poisson term. (For values of P_s near unity, this is an approximation to $\log_e$ additional assurance from the nth spare.) Record r at the top of (12) and calculate C_r for each type by multiplying (11) by r for every part class to be optimized.

Determine Numbers of Spares for Trial r. From Molina, Table I, select the largest value of n (called x in Molina) for the proper value of λ (called a in Molina) that yields a tabular entry just exceeding the value of C_r in Column (12). Enter this number in column (13).

Determine $\log_e$ Probability of Spares. Using Molina, Table II, enter for the same value of λ the term for

$$\sum_{x=n+1}^{\infty} \frac{e^{-\lambda}\lambda^x}{x}$$

in column (14).

Calculate Assurance of Kit. Determine the probability of adequacy of a kit composed of the number of spares noted for each item in column (13) as the antilog to base e of minus the sum of (14).

Calculate Cost of Kit. In column (15), enter the product of price (11) times the quantity of spares in column (13). The sum of column (15) is the cost of the spares kit. Computation of one point on the cost-assurance curve is complete.

Compute Other Points on the Cost-Assurance Curve. If necessary, pick another value of r and repeat the steps from Determining the Number of Spares for Trial r through the Calculation of Kit Costs, using a supplementary worksheet. Where a range of assurance is wanted, time spent looking up values in Molina's tables can be reduced by repeating steps for several values of r simultaneously. After two or more points on a cost-assurance curve have been calculated, values of r for any particular assurance or cost can be interpolated by graphic examination of the curve. In selecting a value of r, note that assurance and cost vary inversely with r.

Account for Non-optimized Essential Parts. Spare parts not included in the optimization must also be supplied. All such parts should be included so that the adequacy of each type is at least 0.9999, (quantity selected using Molina, Table II). Using the value of expected failures appearing in column (9), record numbers of spares required in (16). Calculate the cost of non-optimized essential spares, using the sum of columns (17). Add this to cost of optimized spares to determine cost of total kit of essential spares. Calculate the probability of adequacy of non-optimized essential spares as a group, which is approximately 1 - (number of types supplied at the 0.9999 level times 10^{-4}). The product of the probability times the probability of adequacy of the optimized spares is total essential kit probability.

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SPARES AND SYSTEMS AVAILABILITY

Dr. Herchel E. Lynch William J. Vanden Bosch Ronald D. Oglesby

ASQC Descriptors: 880, 613, 632, 821, 863

Key Words: Availability, Analyses, Logistics, Maintainability, Predictions, Trade-Off Analyses

Abstract

An approach is developed to analyze the effects of different sparing levels on system availability. Important sparing parameters derived are: the probability density function of the system's availability; the time between restocking the spare supply; number of spares for a probability level that a spare will be available; the expected system down time due to lack of a spare; the number of spares for the lowest cost; and the average and minimum system availability. An example of the analysis of a system is shown to illustrate the method. The approach presented in based on approximations using the Central Limit Theorem and its asymptotic properties. The authors feel that these approximations are accurate enough when one considers that this method will be utilized in the early phases of the system's life and that only limited data will be available.

Introduction

At present, no simple methodology exists for the early prediction of system operating characteristics which is accurate enough for major parameter trade-offs, can be applied without knowledge of the detailed system parameters and is flexible enough to be applied to many different types of systems. During the early stages of the system's life cycle there is a great need for a methodology to predict the following characteristics:

A

1. The probability a system is operating, either in the transient or steady state.

2. The probability distribution of the total operating time during a calendar time interval.

3. The probability distribution for the number of failures and repairs which occur during the time interval.

S

4. The number of spares necessary to achieve an effectiveness goal.

5. The expected time the system is down due to no spares being stocked.

6. The effect of a sparing policy on the system's availability.

This information is required to perform the trade-offs necessary for a system and cost effectiveness study. An approach to solving these problems is presented in this paper through the utilization of renewal process theory and its asymptotic behavioral properties. If the designer has this methodology available to predict the life characteristics of the system, he can then estimate the following operating characteristics of the system to evaluate competing designs: availability, mission reliability, operational readiness, preventive maintenance and sparing policy, and total system life cycle costs.

This paper keys on two of these important system figures of merit, the availability and the sparing policy. It should be noted that characteristics #1 and #2 pertain to the prediction of the availability of a system and characteristics #3, 4 and 5 pertain to the sparing policy.

Each of the above operational characteristics have been investigated individually in recent articles, and a few publications have combined them. Each of the operational characteristics can be difficult to predict, but when several are combined, the solutions have been obtained mostly by large scale costly computer simulations. The primary purpose of this article is to provide a simplified approach for determining the effects of a sparing policy upon the system availability (characteristic #6 above). The approach presented does not require complicated calculations nor a knowledge of probability and statistics.

Availability and Sparing Predictions

Many authors (Refs. 1, 10-11, 13, 15) have provided techniques and solutions for the problem of predicting the availability of a system or groups of systems which undergo alternate operation and repair cycles. The operating and repair cycles in these references are identical to a system operating with an infinite number of replacements, where the repair time shown is actually a replacement time. The reader is referred to reference 10 which is a review of a number of methods used to calculate the system availability.

One of the major tasks in developing a support concept is the determination of the number of spares that an equipment will require. The importance of an adequate number of spares has long been recognized by both the Department of Defense and by private industry as a critical factor in determining whether or not operational requirements are met. Inadequate determination of spare parts can result in higher system and storage costs if too many parts are stocked, or in excessive down-time if too few parts are on hand. The questions that need to be answered are:

1. How many spares will have to be stocked in order to meet a desired probability level that enough spares are available;

2. How many spares need to be stocked to assure that an economic minimum of system down-time will occur?

Many approaches (Refs. 2, 4-9) to this problem have been presented and these are generally divided into two categories:

1. Those which make assumptions which limit the range and applicability of the technique such as sparing for the expected

number of failures, assuming a constant failure rate/poisson process or sparing a system based on only the total operating time.

2. Those approaches that require a computer simulation, which range from the simple to the very complex and sophisticated models, but require a computer program, a computer, computer time and available personnel.

Until 1971, there was not a convenient model for predicting adequate numbers of system spares which could be applied to a wide range of systems and could be used by the designer or others who do not normally have a statistical background. However, at the Reliability and Maintainability Symposium in 1971. McNichols (Ref. 9) presented a paper which provided a simplified technique for determining the number of spares necessary for a system or groups of systems utilizing a prechosen probability level that sufficient spares would be available. The basis for this technique was the fact that the density function of a sum of independent random variables approaches the normal density function, regardless of the type of density function each of the variables had. Using this fact, an asymptotic approximation proposed by Cox (Ref. 3) and Barlow (Ref. 1) and extensions by McNichols, a technique was shown which would provide an estimate of the number of spares needed for the prechosen probability level; for any type of basic process probability density function, for any of the process sequences shown, and for single and multiple sparing policies. This was possible through utilization of the simplified tables, graph, and the step-by-step technique shown in this paper, along with calculations which are not complicated nor difficult and which do not require any knowledge of probability or statistical theory.

Oglesby (Ref. 12) utilized a computer simulation to verify the above procedure for certain sparing configurations. His investigation covered three systems with different probability density functions of times to failure. Vanden Bosch (Ref. 18) tested the technique both analytically and by simulation. Both found that the simplified technique provided accurate predictions for a number of differing probability distributions and sparing configurations.

The Approach

The approach presented in this article can best be illustrated by the development of an example system analysis using a combination of the techniques and results previously discussed. The example system has the following characteristics:

1. It undergoes an alternating failure and repair process following the assumptions from McNichols (Ref. 9) with mean time to failure of $1/\lambda$ ($\lambda = .1$) and mean time to install spare of $1/\mu$ ($\mu = .5$).

2. The spares are drawn as needed from a stock which is replenished every T hours.

3. The cost of a spare is $510 each, the system down-time costs are $100 per hour, the order cost is $25 per order and the carrying costs are $1.157 per spare per day.

4. The probability density functions are assumed to be exponential.

In the system analysis we desire to predict the following:

1. The expected system availability and the probability density function of the system availability.

2. The number of hours between restocking the spare supply, T.

3. The number of spares necessary for the system to last T hours with a probability of $P_{1-\alpha}$.

4. The expected time that the system will be down due to lack of spares.

5. The number of spares which provide the lowest costs.

6. The average expected availability and the expected availability and the minimum expected availability.

Prediction of System Availability (Transient, Steady State, Interval

Sandler (Ref. 15) provides the solution for a system with characteristics 1 and 4. This solution could also be used to describe a system with an infinite number of spares ($n = \infty$) where $1/\mu$ is the mean time to install a spare in lieu of being repaired as in Sandler's solution. The probability that the system is operating at t, which is equal to the time dependent transient system availability, $A(t, n = \infty)$.

$$A(t,\ n = \infty) = \frac{\mu}{\lambda + \mu} + \frac{\lambda}{\lambda + \mu} e^{-(\lambda + \mu)} \quad \text{for } t \geq 0 \tag{1}$$

assuming that the system is operating at $t = 0$. Eq. 1 provided the prediction of the expected system availability.

The probability density function of the system availability can be predicted using a result obtained by Takacs (Ref. 17). He proved that the total operating time, t_0, occurring in a system such as this during a total time period, t, was asymptotically normal with a

$$\text{Mean of } t_0 = \frac{\frac{1}{\lambda}}{\frac{1}{\lambda} + \frac{1}{\mu}}\, t = \mu_{t0} \tag{2}$$

and

$$\text{Variance of } t_0 = \frac{\frac{2}{\lambda^2\mu^2}}{\left[\frac{1}{\lambda} + \frac{1}{\mu}\right]^3}\, t = \sigma^2_{t0} \tag{3}$$

provided the variances of the probability density functions were not zero. We should realize that this is an approximation. However, considering the time frame during which these predictions are being made, it is felt that this approximation will be as accurate as the input data concerning the system parameters. From this result and the fact that an estimate of the system availability is

$$A(t) = \frac{\text{total operating time}}{\text{total time}} = \frac{t_0}{t}\,. \tag{4}$$

Then at any point t, after several cycles have elapsed, the probability density function of A(t) can be estimated by the normal probability density function with

$$\text{Mean of } A(t) = \mu_A = \frac{\frac{1}{\lambda}}{\frac{1}{\lambda} + \frac{1}{\mu}} \tag{5}$$

and

$$\text{Variance of } A(t) = \sigma_A^2 = \frac{2}{\left[\mu^2\lambda^2\right] \left[\frac{1}{\lambda} + \frac{1}{\mu}\right]^3 t} \tag{6}$$

The time dependent expression for A(t) (Eq. 1) from Sandler can also be used with the variance of A(t) (Eq. 6) from Takacs in some cases to provide a better prediction. Calculation of the quantities discussed thus far provides

$$A(t, n = \infty) = \frac{.5}{.1 + .5} + \frac{.1}{.1 + .5} e^{-(.1 + .5)t}$$

$$= \frac{5}{6} + \frac{1}{6} e^{-.6t} \tag{7}$$

$$\mu_A = \frac{.5}{.1 + .5} = \frac{5}{6} \text{ hrs.} \tag{8}$$

$$\sigma_A^2 = \frac{\frac{2}{(.1)^2 \ (.5)^2}}{\left[\frac{1}{.1} + \frac{1}{.5}\right]^3 t} = \frac{.4629}{t} \tag{9}$$

For example, at t = 56 hrs., these would provide

$$A(t, n = \infty) = \frac{5}{6} + \frac{1}{6} e^{-(.6)\ (56)} = .833 \tag{10}$$

$$\mu_{t_0} = \left[\frac{5}{6}\right] (56) = 46.67 \text{ hrs.} \tag{11}$$

$$\sigma_{t_0}^2 = (.4629)\ (56) = 25.92 \text{ hrs}^2 \tag{12}$$

$$\Pr\left[\mu_{t_0} - 1.65\sigma_{t_0} \le t_0 \le \mu_{t_0} + 1.65\sigma_{t_0}\right]$$

$$= \Pr\left[38.3 \text{ hrs.} \le t_0 \le 55.07 \text{ hrs.}\right] = .90 \tag{13}$$

and

$$\Pr\left[\mu_{t_0} - 1.28\sigma_{t_0} \le t_0\right]$$

$$= \Pr\left[40.15 \text{ hrs} \le t_0\right] = .90. \tag{14}$$

Also,

$$\mu_A = \frac{5}{6} = .833 \qquad \sigma_A^2 = .00827 \tag{15-16}$$

$$\Pr\left[\mu_A - 1.65\sigma_A \le A(t) \le \mu_A + 1.65\sigma_A\right]$$

$$= \Pr\left[.683 \le A(t) \le .983\right] = .90. \tag{17}$$

$$\Pr\left[\mu_A - 1.28\sigma_A \le A(t)\right]$$

$$= \Pr\left[.717 \le A(t)\right] = .90. \tag{18}$$

These calculations provide several probability bounds for the total operating time (t_0) in 56 hours and for the system availability $|A(t, n = \infty)|$.

The average system availability (interval availability) over the time interval, 0 to t, can be found using

$$A_I(T) = \frac{1}{T}\int_0^T A(t, n = \infty)dt = A_{ave}$$

$$= \frac{5}{6} + \frac{1}{3.6T} - \frac{1}{3.6T}e^{-.6T} = .833 \tag{19}$$

In latter calculations, A(t, n = n) will also be used in Eq. 19.

<u>Restocking Interval</u>

McNichols (Ref. 9) provides a method of finding the number of spares necessary to operate a work time of T hours with the probability of $P_{1-\alpha}(n)$ that enough spares will be in stock. The first quantity that must be determined is the restocking time period T. With a few simplifying assumptions, the economic order quantity could be obtained for our example as follows:

$$T = \sqrt{\frac{2C_3}{C_1 R}} = \sqrt{\frac{(2)(25)}{(1.157)(.833)}}$$

$$= 7.2 \text{ days} = 72 \text{ hours.} \tag{20}$$

T = Reorder time in workdays

C_3 = Order Costs = $25.00

C_1 = Costs to carry one spare for one day = $1.157

R = Rate of usage in days

$$= \frac{\text{number of work hour/day}}{\text{Average cycle time}} = \frac{10}{12} = .833$$

$$\text{Where average cycle time} = \frac{1}{\lambda} + \frac{1}{\mu} = \frac{1}{.1} + \frac{1}{.5}$$

$$= 10 + 2 = 12$$

This would indicate that the spare stock should be replenished every 72 hours with constant demand with no lead time. Other inventory models based on a closer estimate of the actual situation could also be used.

<u>Prediction of Number of Spares</u>

Using McNichols method (Ref. 9) to calculate the number of spares necessary for a total time of 72 hours with a probability level of $P_{1-\alpha}(n) = .75$, we find that the example system is identified as a Class B.2 and system configuration Type 1. His equations provide

$$u'_p = (n + 1)\left[\frac{1}{\lambda} + \frac{1}{\mu}\right] - \left[\frac{1}{\mu}\right] = (n + 1)\ (12) - (2) \tag{21}$$

$$\sigma_p^2 = (n+1)\left[\frac{1}{\lambda^2} + \frac{1}{\mu^2}\right] - \left[\frac{1}{\mu^2}\right]$$

$$= (n+1)\ (104) - (4) \tag{22}$$

$$Z_{1-\alpha}(n) = \frac{\mu_p' - T}{\sqrt{\sigma_p^2}} = \frac{\mu_p' - 72}{\sqrt{\sigma_p^2}} \tag{23}$$

Evaluating these equations, we find

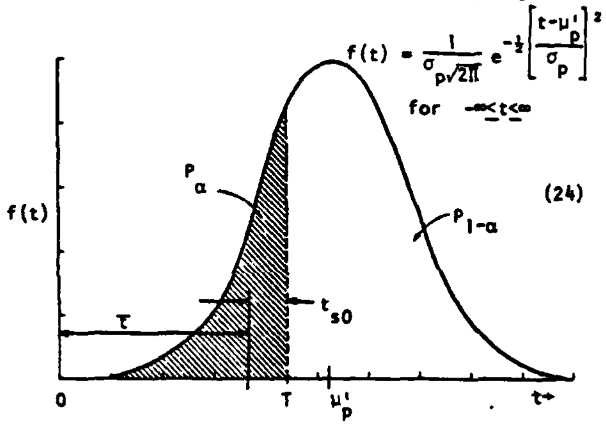
for $n = 6$ $\quad Z_{1-\alpha}(6) = .372 \quad P_{1-\alpha}(6) = .64$

for $n = 7$ $\quad Z_{1-\alpha}(7) = .765 \quad P_{1-\alpha}(7) = .78$

Thus, 7 spares per 72 hours sparing cycle would be required to provide a probability level of .78.

Expected Stock-Out Time

Another quantity important in the system analysis is the expected time that the system will be down due to no spares being in stock. McNichols (Ref. 9) states that the density function of the time of failure of the last spare could be approximated by a normal density function with a mean of μ_p' and a variance of σ_p^2 shown above. This provides the following figure:



(24)

Figure 1 - Normal Density Function

From this, the expected stock-out time given a stock-out occurs can be found to be:

$$t_{s0} = T - \bar{t} = T - \frac{1}{P_\alpha}\int_{-\infty}^{T} t f(t)dt$$

$$= T - \mu_p' + \frac{\sigma_p^2\, f(T)}{P_\alpha} \tag{25}$$

The expected stock-out time for the system with n spares in stock is given by

$$\bar{t}_{s0}(n) = \left[t_{s0}(n)\right]\left[P_\alpha(n)\right] + \left[0\right]\left[P_{1-\alpha}(n)\right]$$

$$= \left[P_\alpha(n)\right]\left[T - \mu_p' + \frac{\sigma_p^2\, f(T)}{P_\alpha}\right]$$

$$= \left[P_\alpha(n)\right]\left[T - \mu_p'\right] + \sigma_p f(Z) \tag{26}$$

Where $Z = \dfrac{T - \mu_p'}{\sigma_p}$

Eq. 26 can be evaluated by using the tables for the standard normal probability density giving the following results:

for $n = 6$, $\bar{t}_{s0}(6) = 6.45$ hours, and

for $n = 7$, $\bar{t}_{s0}(7) = 3.67$ hours.

The quantities are the expected stock-out times for the system given a certain number of spares are stocked.

Combining System Availability and Sparing Predictions

It should be noted that if a system does not experience a stock-out during this time period, 0 to t, the probability that the system is available is as shown for the case of infinite spares. However, if a stock-out does occur, then at that point the system availability goes to zero and is no longer available during the period from which a stock-out occurs to the time point T. If the system is spared with n spa[illegible] then the probability that the system will not be [illegible] due to lack of spares during this time period T [illegible] $P_{1-\alpha}(n)$ which is the probability that a stock-out does not occur.

First, let us confine our discussion to those systems which do not experience a stock-out prior to T. The time dependent availability of these particular systems is the probability that the system is operating at t. This probability is actually a conditional probability, i.e., the probability that the system is operating given that the time of the n + 1 system failure, t', is greater than T. Thus,

$A(t, n = \infty)$ = Probability that the system is operating given the number of spares = ∞ (27)

and

$P_{1-\alpha}(n)$ = Probability that t' > T given n spares (28)

Therefore

$$A(t, n = n) = \left[A(t)\right]\left[P_{1-\alpha}(n)\right]$$

= Probability that system is operating and t' is greater than T with n spares. (29)

For the example system:

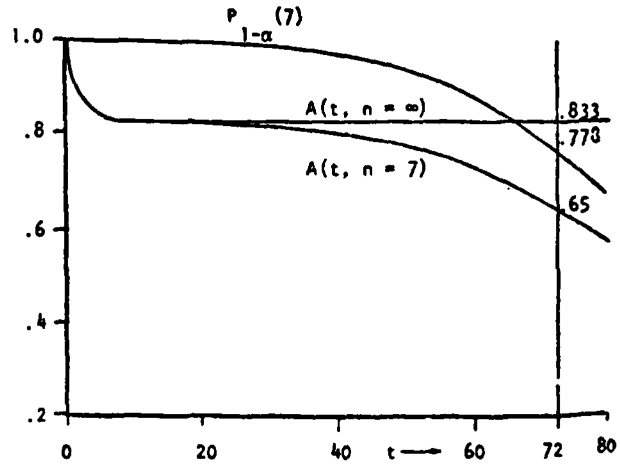


Figure 2 - Values for Example System

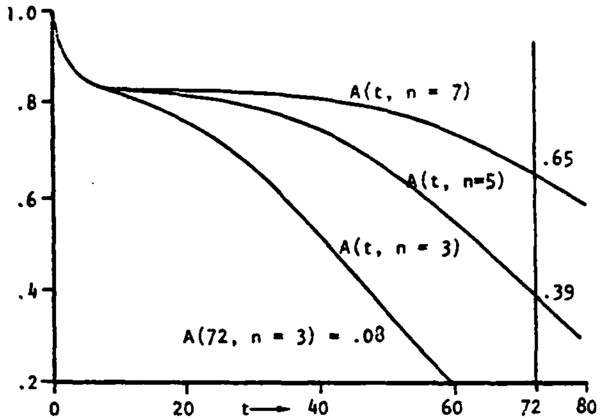


Figure 3 - Different Sparing Policies

Economic Analysis

The following type of information can now be calculated for our example system. The costs of the spares was C_s = \$510.00, and the equipment down-time due to lack of spares was C_D = \$100.00 per hour.

$$\text{Total Costs} = (n)\ (C_s) + (\bar{t}_{s0})\ (C_D) \tag{30}$$

n	$P_{1-\alpha}$	A_{min}	A_{ave}	$\bar{t}_{s0}$	Cost of Spares	Downtime Costs	Total Costs
3	.10	.08	.51	26.99	1530.00	2699	4229
4	.27	.22	.62	17.80	2040.00	1780	3820
5	.46	.39	.70	10.88	2550.00	1099	3649
6	.64	.54	.75	6.45	3060.00	645	3705
7	.78	.65	.79	3.67	3570.00	367	3927
8	.87	.72	.81	2.01	4080.00	201	4281
9	.92	.77	.82	1.12	4590.00	112	4702
∞	1.00	.933	.83	0			

Table 1 - Summary

From a table such as this, the system could be reviewed to see if the goals or specifications have been met.

Utilizing the procedures shown herein specifications or goals could be set in the early life of a system on each of the following or any combinations, for example,

1. Probability that spare is in stock $= P_{1-\alpha} \geq .75$ n = 7
2. Minimum system availability $= A_{min}\ (t, n = n) \geq .70$ n = 8
3. Average system availability $= A_{ave}\ (t, n = n) \geq .75$ n = 6
4. Maximum expected stock-out time $= \bar{t}_{s0} \leq 4.0$ n = 7
5. Minimum cost n = 5

A demonstration plan can be devised based on the availability density function.

Summary

It is felt that a person who has been struggling with the problems associated with a sparing policy and with predicting the availability of a system, either in the early or middle stages of its life cycle, can easily grasp the benefits from a simplified technique such as this one. The approach is versatile and relatively uncomplicated.

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Biographies

Mailing address: Dr. Herchel E. Lynch
USAMC Intern Training Center
Red River Army Depot
Texarkana, TX 75501

Dr. Herchel E. Lynch was one of the developers of the US Army Materiel Command Graduate Engineering Programs at the USAMC Intern Training Center, Red River Army Depot, Texarkana, Texas. Initiated in 1965 and 1969, these programs are in the fields of System Safety, Maintainability, Maintenance and Production Design. His Ph. D. and Master's were attained in Industrial Engineering (System Engineering and Analysis) and his B.S. Degree was in Civil Engineering (Structural Design), all from Texas A&M University. Since 1965, he has served in various teaching, research and management positions at the Center and presently is serving as Research Coordinator for the Center. In addition to his activities there, he has served on several Department of the Army AD-HOC Committees in the system analysis and modeling areas. He has authored and presented numerous articles in the RAM and Systems Engineering areas. Presently, he is a Senior Member in the AIIE, serving on the Editorial Board of the AIIE Transactions, an Executive Board member of the ArkLaTex Chapter of the Association of the US Army, performs private consulting engineering and teaches Business Administration courses for East Texas State University at Texarkana. Prior to coming to the Center, he had taught at Texas A&M University and had eight years of varied engineering consulting and management experience in Texas. He is a member of three engineering honor societies, several professional organizations and is a Consulting Engineer registered in the State of Texas.

Mailing address: Mr. Ronald D. Oglesby
US Army Materiel Command
ATTN: AMCMA
5001 Eisenhower Avenue
Alexandria, VA 22333

Mr. Ronald D. Oglesby is a Mechanical Engineer with the Directorate of Maintenance at Headquarters, US Army Materiel Command, and is responsible for providing engineering analysis, planning, policy, program system development, field staff supervision and RAM expertise on combat vehicles, marine, rail, construction and general equipment. Mr. Oglesby received his B.S. in Aerospace Engineering from Mississippi State University in 1970 and his M. E. Degree in Industrial Engineering (Maintainability Option) from Texas A&M University in 1972.

Mailing address: Mr. William J. Vanden Bosch
US Army Materiel Command
ATTN: AMCMA
5001 Eisenhower Avenue
Alexandria, VA 22333

Mr. William J. Vanden Bosch is currently assigned to Headquarters, US Army Materiel Command, as a General Engineer in the Directorate for Maintenance and is responsible for providing engineering analysis, monitoring system development, developing plans, policy and RAM expertise on Army Aircraft Systems. He received a B. S. in Aerospace Engineering from the University of Texas in 1967 and worked for General Dynamics, Ft. Worth, Texas, for five years in performance analysis, and predesign development of aircraft systems. He received his M.E. Degree in Industrial Engineering (Maintainability Option) in 1972 from Texas A&M University.

Ms. Sandra L. McLaughlin is a staff member at the USAMC Intern Training Center. As a part of her position, she participates in the editing and preparation of many research papers with the members of the faculty at the Center. The authors want to express their appreciation for her efforts on this research project.

31)

A MONTE CARLO APPROACH TO SPARES PROVISIONING

R. L. Sebeny

Collins Radio Company

Cedar Rapids, Iowa

Summary

Computer programs employing a Monte Carlo approach to simulate system operation provide a versatile means of solving a variety of reliability and maintainability problems. Presented in this paper are descriptions of major program functions together with a discussion of an application of this technique to a spares provisioning problem.

Introduction

In the design of a system and its support facilities, the ability to conduct quantitative trade-off analyses is essential. This task becomes difficult when the parameter to be optimized is system availability and the system exhibits the following features.

1. The system configuration contains redundancy such as parallel units or parallel subsystems consisting of a number of units.

2. The system contains similar unit types that may be, under certain conditions, interchanged or cannibalized. The similar unit types may also be supported from a common source of spares. Both of these features make the subsystems, containing the similar units, dependent.

3. Failed assemblies are either repaired at the system location or replaced from an off-site depot. Thus, the system and its complement of spares is continually renewed.

An approach to the task of selecting spares for a system with the above features is described together with a description of the major elements of the approach and a description of a typical application.

Approach

With the use of a computer, actual system operation can be rapidly and accurately simulated. Various parameters, such as those required to make systems reliability and availability predictions can then be generated and used in the same manner as actual in-service observations. For example, system availability is calculated by dividing the operative or "up" time obtained through simulation by the total simulated time or the sum of "up" and "down" time, expressed as

$$\text{Availability} = \frac{\text{Up Time}}{\text{Up Time} + \text{Down Time}} \qquad (1)$$

$$\frac{1}{1 + \lambda \mathrm{MTTR}}$$

The major functions required to simulate system operation include a failure generator, a check routine to measure the degree of agreement between the failures simulated and expected, and a test routine to determine if a particular combination of unit failures results in a system failure.

Failure Generator

It is required that this function generate failures within a system in the same manner anticipated for the system under actual operating conditions. Where individual unit failures are expected to follow an exponential probability distribution function, the generator must produce failures randomly and at a rate approximately equal to the constant failure rate of each unit.

Failure generation can be performed by comparing a random number, R, taken from a uniform distribution bounded by 0 and 1.0, to the probability, P(O), of having no unit failures during an increment of time, ΔT, expressed as

$$P(O) = e^{-\lambda_t \Delta T} \qquad (2)$$

where λ_t is the sum of the individual operating units in the system.

If one or more failures did occur during the time increment, then $R > P(O)$. The same random number is then used to determine how many failures, r, occurred during ΔT by satisfying the following inequality containing terms of the Poisson distribution.

what is λ

$$\sum_{X=1}^{r-1} \frac{(\lambda \Delta T)^X e^{-\lambda \Delta T}}{X!} < R < \sum_{X=1}^{r} \frac{(\lambda \Delta T)^X e^{-\lambda \Delta T}}{X!} \qquad (3)$$

To determine which units of the system failed during ΔT a random number, R, for each of the r failures, is used in the solution for I in the following inequality.

$$\frac{1}{\lambda_r} \cdot \sum_{I=1}^{I} \lambda_I > R \qquad (4)$$

λ

where λ_T is the sum of the failure rates of those operating units still remaining in the system and λ_i is the failure rate of the i^{th} operating unit. This process is analogous to randomly throwing a dart at a board having the area λ_T and divided into subareas which are proportional in size to the individual unit failure rates. For multiple failures, the subareas are reapportioned with each selection.

Check Routine

In order to ensure that the various units of a system have been failure-sampled an acceptable number of times during simulation, a chi-square goodness-of-fit test can be employed, expressed as.

$$\chi^2 = \sum_{i=1}^{K} \frac{(o_i - e_i)^2}{e_i} \qquad (5)$$

where K is the number of operational units in the system, o_i is the number of failures accumulated for the ith unit, and e_i is the number expected during the period simulated. The calculated chi-square value, χ^2, is compared to the chi-square distribution having K-1 degrees of freedom to determine the probability of obtaining the calculated χ^2 value by chance.

Test Routine

The method used to determine the effect of unit failures on a system involves comparing the current unit states (up or down) to a system "success" table. The table is constructed to contain all possible combinations of unit states that will result in system success. The configuration of Figure 1 would have the

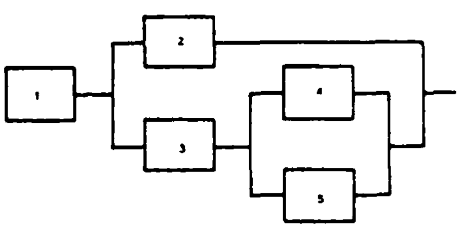

Figure 1. Example Configuration

"success" table, shown in Table 1, wherein the letter U indicates that a unit must be "up" for a particular combination of units. Blanks indicate that the particular unit may either be "up" or "down."

Table 1. Example Success Table

SUCCESS COMBINATION NUMBER	UNIT				
	1	2	3	4	5
1	U	U			
2	U		U	U	
3	U		U		U

If a particular combination of unit "up" states fails to match at least one table row then the test would result in a system failure.

The creation of a system "success" table can be computerized therefore requiring only the unit interconnections as input for a given system. Required is a computer program capable of establishing all possible paths through the system network.

Problem Application

The flow diagram of Figure 2 summarizes the program logic involved in using simulation to solve a spares provisioning problem. The steps are as follows:

Step 1. System operation is simulated by using a failure generator to determine if there were one or more unit failures in the system during an increment of time, ΔT. The system, for this step, is considered complete in that all normally operating units are subject to failure.

If a failure occurred the flow would be to step 2; if not, ΔT would be added to an "up" time counter and step 1 would be repeated.

Step 2. With the occurrence of one or more unit failures, the test routine of step 2 is used to determine whether or not the unit failure(s) resulted in a system failure. If system failure did occur, the flow would be to step 3; if not, ΔT would be added to the "up" time counter and the flow would be to step 4.

Step 3. This step simulates those maintenance actions that would be expected to take place in actual system operation. Involved may be a check to see if spares are available or other similar units within the system can be cannibalized to replace failed units. Also, on-site repair action may be initiated or the unit may be replaced or repaired at an off-site depot requiring an extended waiting period. In any event those repair actions that can be implemented within the ΔT time increment are effected by changing the unit states from "down" to "up."

The test routine of step 2 is again used to determine if the system failure has been corrected. If it has not then ΔT is added to a "down" time counter and the responsible unit(s) noted with the flow then proceeding to step 4. If the system has been returned to satisfactory operation, the repair time is added to the "down" time counter and the remainder of the ΔT in-

crement added to the "up" time counter. The flow then proceeds to step 4.

Step 4. A check is made at this point to determine if the system has been renewed to the initial conditions, i.e., return to state of each normally operating unit for an "up" condition. If the system has been renewed, flow is to step 6; if not, then to step 5.

Step 5. This step involves the same program logic as step 2 except that only those units in an "up" state are considered as failure sources. In addition to testing for unit failures during the time increment ΔT, all maintenance or waiting actions that may be underway are advanced by ΔT. Flow then reverts back to step 2.

Step 6. At the completion of a failure-repair cycle, a check routine is used to determine if results of the simulation satisfactorily agree with the results expected. Also, at this point, a test may be incorporated to determine if a steady-state availability value has been obtained. This may be accomplished by testing the difference between the current availability value and the average of the previously calculated values. If the sampling proves adequate, the flow is to step 7; if not, flow reverts back to step 1.

Step 7. The accumulated system "up" time and "down" time is used to calculate system availability with the expression given in equation (1). Spares provisioning is accomplished with step 8.

Step 8. The accumulated simulation data including the total system "down" time due to each unit type is used to generate a list of system availability values as a function of sparing various unit types, added in a one-at-a-time manner, together with the accumulated spares cost. The order of the list is based on descending values of the ratio of the down time contribution to spares cost for each unit type. Each level of system availability is calculated by subtracting the "down" time that would be eliminated by providing a given spare from the previous total system "down" time value.

Example Problem

A computer program, written in Fortran IV and currently being run on a CDC 6400 computer, was used to conduct a spares provisioning analysis of the example system shown in Figure 3. Computer output listings containing the input data and solution of the example problem are shown in Figures 4 through 12; explanations of their contents follow.

Figure 4. This listing page contains the indicated problem constants used in the analysis. The system nodes refer to the circled intersection points of Figure 3. The computer program used in solving the example problem develops two types of "success" tables. The first type contains combinations of unit states providing section success, a section being made up of units and providing paths between the system nodes of Figure 3. The second type of success table contains combinations of section states that provide system success. This system approach in setting up success tables greatly reduces the number of possible unit-state combinations required for a large system.

The minimum and maximum number of trials shown in Figure 4 are used to control the number of failure-repair cycles simulated in the solution. The minimum number prevents a premature halt of the solution where no system "down" time has occurred and an availability value of 1.0 would appear to be a good steady-state solution. The maximum is provided to halt a solution that may not normally terminate due to either unrealistic problem constants or errors in the input data.

The increment period, ΔT, is specified in the example as 4.0 hours and the time required to replace a failed unit from an off-site depot is six increments or 24 hours.

A number, which will be the starting number for the sequence of generated random numbers used in the solution, is inputted so that a particular solution can be exactly duplicated if so desired.

Figure 5. Input data pertaining to the various unit types contained in the example system is shown in this figure. Shown are the failure rates, relative spares cost, and replacement time of each unit type. Included also is the number of spares that are initially provided for each unit type which in the example problem are zero for each type. The column headed Status allows the program user to prohibit a particular unit type from being considered for sparing. In the example problem all unit types are assigned a zero status thus making each a candidate for sparing.

An added feature of the computer program is provisions for preventative maintenance of certain unit types. The program will periodically place units of a certain type in a down state for a prescribed duration in order that cyclic preventative maintenance actions may be simulated. The column headed INCS TO PM indicates the frequency of the maintenance action which for unit type number 4 is 360 four-hour increments or every 1440 hours. The time required to carry out the maintenance action is contained in the column headed PM INCS.

Figure 6. This page of listing shows the interconnection configuration and unit type complement of the first system section. The unit interconnection is referenced to system nodes shown as solid dots in Figure 3. For example section 1 described in Figure 6 lists the unit node connection sequentially which indicates a serial configuration. Section node 1 always corresponds to the system node at which a section starts whereas the last section node corresponds to the system node where the section ends. Thus for section 1 node 4 corresponds to system node 2 as shown in Figure 3.

There are similar output listings for the other system sections.

Figure 7. This listing page summarizes the data accumulated during simulation. Listed is the final steady-state availability value, the number of simulation trials performed, and the chi-square goodness-of-fit probability obtained at the completion of the simulation. System output parameters are presented as the average number of system outages per year, the average system down time per outage, and the average total system down time per year.

Figure 8. This listing page contains the results of the spares trade-off analysis. Each line of output shows the spare unit type selected in order of preference. Listed are the unit type name and various system parameter values that would result if the spare unit type was provided.

The same problem was again run but with a spare A-2 type unit. The resulting solution is shown in Figures 9 and 10. The output listing containing the input data and section descriptions would be the same for this problem as those of Figures 4 through 6 with the exception of one spare being shown for unit type A-2 in Figure 5.

Conclusion

The program described in the paper illustrates a method of provisioning spares for a complex system on the basis of their impact on system availability and cost. Through the use of a Monte Carlo technique, a wide variety of system configurations and maintenance practices can be simulated and analyzed. Also, by employing a computer generated table describing system success as a function of assembly states, the input data required to use the program is greatly simplified. Input data is "user" oriented requiring only knowledge of system operation and maintenance practices thus permitting use of the program by personnel of varied disciplines.

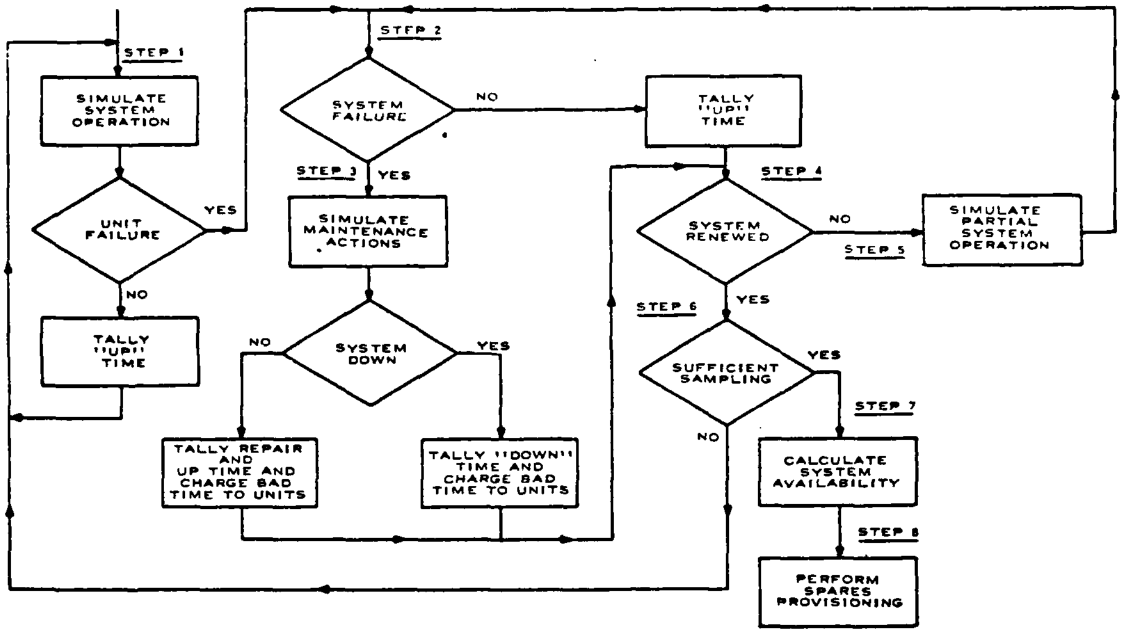

Figure 2. Spares Provisioning Program, Flow Diagram

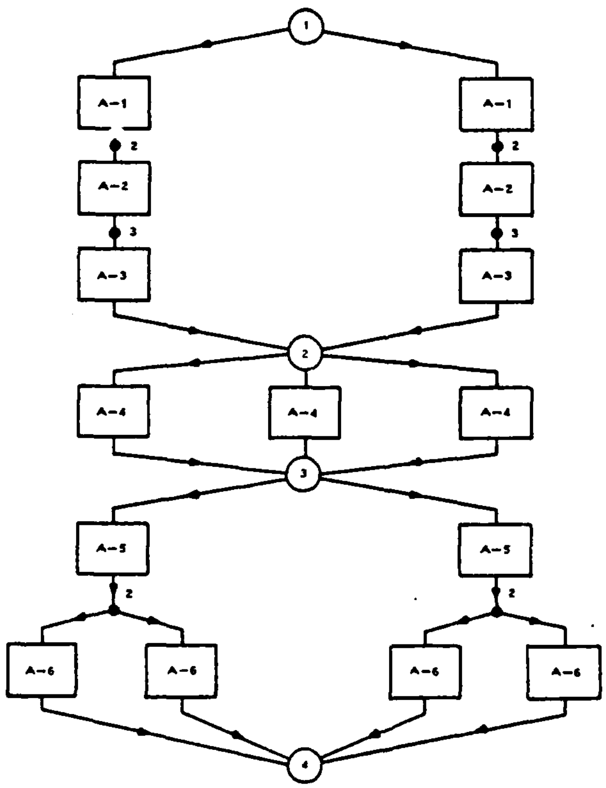

Figure 3. Example Problem System, Block Diagram

SYSTEM - EXAMPLE PROBLEM NO. 1	ORIGINATOR - R SERENY
PROBLEM/SYSTEM CONSTANTS	
NO. OF SYSTEM NODES -- 4	
MIN. NO. OF TRIALS --- 500	
MAX. NO. OF TRIALS --- 5000	
INC. TIME PERIOD(HRS) 4.00	
NO. OF INCS. IN TURN-AROUND PERIOD --- 6	
RANDOM NO. 74488279156793	

Figure 4. Example Problem Output Listing - Problem/System Constants

UNIT INPUT DATA

NO.	TYPE	FR X10-5	COST	REL TIME(HRS)	NO. SPARES	STATUS	INCS TO PM	PM INCS
1	A-1	75.000000	20	0.100	0	0	0	0
2	A-2	110.000000	25	0.100	0	0	0	0
3	A-3	47.000000	10	0.100	0	0	0	0
4	A-4	376.000000	75	0.100	0	0	360	2
5	A-5	75.000000	20	0.100	0	0	0	0
6	A-6	278.000000	47	0.100	0	0	180	1

Figure 5. Example Problem Output Listing - Unit Input Data

SECTION 1 INPUT DATA

NO. OF UNITS 3,NO. OF NODES 4,MIN. NO. OF PATHS FOR SUCCESS 1

THE SECTION STARTS AT SYSTEM NODE 1 AND TERMINATES AT NODE 2

UNIT NO.	LOC. NO.	TYPE	START NODE	TERM NODE
1	1	A-1	1	2
2	2	A-2	2	3
3	3	A-3	3	4

Figure 6. Example Problem Output Listing - Section 1 Input Data

BASELINE SYSTEM PERFORMANCE DATA
SYSTEM AVAILABILITY 0.99952315
NUMBER OF TRIALS 515
FIT PROBABILITY 0.93922717
NUMBER OF OUTAGES PER YEAR 1.60
AVERAGE OUTAGE TIME 8.10 HOURS
TOTAL OUTAGE TIME PER YEAR 12.95 HOURS

Figure 7. Example Problem Output Listing - Baseline System Perform and Data (Initial Run)

SPARES LIST

UNIT NO	UNIT NAME	SYSTEM AVAILABILITY	AVG OUTAGE TIME (HRS)	TOT OUTAGE TIME PER YR	UNIT COST	CUM SPARES COST
2	A-2	0.99924981	4.11	6.58	25	25
4	A-4	0.99995167	0.27	0.42	75	100
4	A-4	0.99997703	0.13	0.20	75	175
2	A-2	0.99997971	0.11	0.18	25	200
4	A-4	0.99998177	0.10	0.16	75	275

Figure 8. Example Problem Output Listing - Spares List (Initial Run)

BASELINE SYSTEM PERFORMANCE DATA
SYSTEM AVAILABILITY 0.99925563
NUMBER OF TRIALS 515
FIT PROBABILITY 0.91418397
NUMBER OF OUTAGES PER YEAR 1.59
AVERAGE OUTAGE TIME 4.10 HOURS
TOTAL OUTAGE TIME PER YEAR 6.53 HOURS

Figure 9. Example Problem Output Listing - Baseline System Performance Data (Second Run)

SPARES LIST

UNIT NO	UNIT NAME	SYSTEM AVAILABILITY	AVG OUTAGE TIME (HRS)	TOT OUTAGE TIME PER YR	UNIT COST	CUM SPARES COST
4	A-4	0.99995454	0.25	0.40	75	75
4	A-4	0.99997979	0.11	0.18	75	150
4	A-4	0.99998184	0.10	0.16	75	225

Figure 10. Example Problem Output Listing - Spares List (Second Run)

32

AN OPTIMUM ALLOWANCE LIST MODEL[1]

Mina Haskind Gourary*
The George Washington University
Logistics Research Project

The author discusses a simplified mathematical model of the allowance list, and draws some general conclusions.

1. INTRODUCTION

One of the more difficult problems of naval logistics is the preparation of adequate allowance lists for naval vessels.[2] On the one hand, one must have reasonable assurance that the requirements for consumables and technical spares will be met under most circumstances. On the other hand, one is confronted with the severe limitations of available space aboard ship, with budgetary considerations, as well as with a host of other less important constraints.

This problem is normally solved by the application of judgment based on past experience. The question arises whether or not it is possible to construct a simple mathematical theory of the allowance list problem which will make better use of the available usage data related to some definite program elements (activities upon which consumption of commodities depend).

The problem we shall consider can be stated as follows: How does one properly stock a vessel with the necessary commodities, subject to the limitations of available space? This entails a decision on the number of commodities to be carried, the quantity of each commodity to be stocked, and the relative weight (i.e., "military worth", etc.) to to given each commodity, all subject to the overriding considerations of space. In this paper we shall attempt to treat a somewhat idealized version of this problem by a method which might be extended to more complicated situations.

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*Manuscript received 5 January 1956

[1] Research performed under contract with the Office of Naval Research. The author wishes to express her appreciation to Dr. C. B. Tompkins and Dr. M. A. Woodbury for stimulating and informative discussions. She is also indebted to Dr. I. Heller and Dr. W. H. Marlow for reading the manuscript and for their valuable criticisms.

[2] By an allowance list we mean a listing of distinct commodities (including all classes of naval material, regardless of cognizance) which should be aboard ship for the maintenance of the ship for a specified time period. This listing contains also the quantity of each of these commodities to be stocked. Each commodity is uniquely identified by a specific Standard Navy Stock Number.

We must now define an objective which we shall attempt to achieve by our construction of the allowance list. If we knew exactly what the demand for each commodity would be, we would have no problem. We would simply stock the required amounts aboard ship, if space permitted, or partially aboard ship and partially aboard supply ships or shore facilities and deliver to the ship as its supplies diminished.

The fact of the matter is that we cannot predict the demand with certainty. We can, however, estimate the probability distribution of the demand for each commodity for a given type of ship, under certain known operating conditions, from a statistical analysis of usage data. We can use this information to construct our allowance list in such a way as to minimize the probability of depletion of any one item in a given period. This might be a reasonable criterion for commodities of critical importance. Alternatively, we can choose another criterion to guide us in the construction of our allowance lists. In this paper we shall attempt to construct our allowance list in such a manner as to maximize the average number of demands fulfilled. This is an arbitrary criterion at best. It is a reasonable choice, however, for those items whose usage varies fairly widely and which are not to be replenished by a supply ship at frequent intervals.

2. STATEMENT OF METHOD

Let us outline our method. Consider a given commodity, say α. Let the amount stocked be y_α and the amount demanded be x_α. Let $\phi_\alpha(x_\alpha)$ be the probability that an amount x_α will be demanded during the period under consideration. For the sake of simplicity, we shall consider the case where x_α is a continuous variable and $\phi_\alpha(x_\alpha)$ has the analytic properties required for the existence of derivatives and integrals of the function $\phi_\alpha(x_\alpha)$. Then the average amount demanded will be:

$$E(x_\alpha) = \int_0^\infty x_\alpha \phi_\alpha(x_\alpha)\, dx_\alpha .$$

If the demand x_α is less than y_α, this demand will be met. But if the demand x_α exceeds the amount stocked (y_α), then only an amount y_α can be met; a demand of $(x_\alpha - y_\alpha)$ is then left unfulfilled. On the average, the amount supplied (when y_α is stocked) is:

$$u_\alpha(y_\alpha) = \int_0^{y_\alpha} x_\alpha \phi_\alpha(x_\alpha)\, dx_\alpha + y_\alpha \int_{y_\alpha}^\infty \phi_\alpha(x_\alpha)\, dx_\alpha , \tag{2.1}$$

and the demand left unfulfilled is, on the average,

$$v_\alpha(y_\alpha) = \int_{y_\alpha}^\infty (x_\alpha - y_\alpha)\phi_\alpha(x_\alpha)\, dx_\alpha = E(x_\alpha) - u_\alpha(y_\alpha) . \tag{2.2}$$

We assume the demand for commodity α to be independent of the demand for commodity β. Thus, the average amount supplied of commodity α is dependent only on y_α, not on anything pertaining to commodity β. In practice, this assumption may not always be correct, but it will greatly simplify our analysis.

Our problem now is to choose the set $y_1, y_2, \ldots y_n$ so as to satisfy the condition

$$\sum_{\alpha=1}^{n} c_\alpha y_\alpha = C$$

(i.e., the total cube of items stocked must equal the available space), and simultaneously to maximize

$$U(y_1, \ldots, y_n) = \sum_{\alpha=1}^{n} u_\alpha(y_\alpha),$$

which is the total quantity supplied on the average. Here, c_α is the cube occupied by one unit of commodity α; and C is the total cube available for the storage of all the n commodities. In general, we may wish to attach a different weight, w_α, to each commodity, depending on its importance (i.e., "military worth," etc.) and its unit of issue. We do this by defining $W(y_1, \ldots, y_n)$ as follows:

$$W(y_1, \ldots, y_n) = \sum_{\alpha=1}^{n} w_\alpha u_\alpha(y_\alpha)$$

and maximizing W, subject to the condition

$$\sum_{\alpha=1}^{n} c_\alpha y_\alpha = C.$$

We shall refer to $W(y_1, \ldots, y_n)$ as the "total utility function;" and we shall call $w_\alpha u_\alpha(y_\alpha)$ the "α-th utility function."

Once we have maximized $W(y_1, \ldots, y_n)$ subject to the space constraint, we know the individual y_α's. Given these y_α's, we can compute the average number of the demands for each α that we can fulfill, namely $u_\alpha(y_\alpha)$'s, as well as the average number of the unfulfilled demands, the $v_\alpha(y_\alpha)$. From the $u_\alpha(y_\alpha)$ we obtain the optimum value of $W(y_1, \ldots, y_n)$, which we shall denote by W_0, and call it the "maximum utility function." It should be clear that W_0 is a function of C only, since for a given C the y_α's, and therefore the $u_\alpha(y_\alpha)$'s, are fixed by the maximization procedure. The significance of W_0 will be elucidated in the discussion (see Section 5).

3. RESULTING FORMULAE

The details of the calculation will be relegated to Appendix I. The resulting formulae for the y_α's are:

$$\int_0^{y_\alpha} \phi_\alpha(x_\alpha)\, dx_\alpha = 1 - \lambda \frac{c_\alpha}{w_\alpha}; \quad \alpha = 1, 2, \ldots, n \tag{3.1}$$

$$\sum_\alpha c_\alpha y_\alpha = C, \quad \text{where } \min\left(\frac{w_\alpha}{c_\alpha}\right) \geq \lambda \geq 0.$$

These are $(n+1)$ equations in the $(n+1)$ variables $y_1, y_2, \ldots, y_n$ and λ (where λ is a Lagrange multiplier). They determine the amounts, y_α's, which are to be stocked. Using these values of y_α's, we can compute $u_\alpha(y_\alpha)$ and $v_\alpha(y_\alpha)$, for each α, from equations (2.1) and (2.2).

For some simple distributions, like the exponential, these equations can be solved explicitly for the y_α's and λ. For the more interesting distributions, however, the explicit solution of the equations is not feasible, and an iterative procedure is indicated. We shall illustrate the meaning of these equations and the method of their solution by working out several examples.

In the first example we shall assume all the $\phi_\alpha(x_\alpha)$'s to be normal. This is a fairly important case, since the normal distribution is the limiting continuous form of a wide class of distributions which occur in practice (e.g., the Poisson distribution).

The second example will illustrate the properties of this model when all the $\phi_\alpha(x_\alpha)$'s are logarithmic normal distributions. The reason for this choice is that most of the tests of modern statistics are based on the assumption that some function $g(x)$ of the variable x is normally distributed. In this case we take $g(x) = \ln x$. This distribution is easy to handle analytically, and the numerical results provide an enlightening illustration of the principles involved.

Finally, we shall consider a case where some of the $\phi_\alpha(x_\alpha)$'s are normal while others are logarithmic normal. This will show how the allowance list is to be constructed when commodities are distributed according to several different distributions.

4. NUMERICAL EXAMPLES

Example 1 - The Normal Distribution

Let $\phi_\alpha(x_\alpha)$, for reasons stated above, be the normal probability density functions. Then equations (3.1) become:

$$1 - \lambda \frac{c_\alpha}{w_\alpha} = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{(y_\alpha - m_\alpha)/\sigma_\alpha} e^{-t^2/2}\, dt$$

(4.1)

$$\sum_{\alpha=1}^{n} c_\alpha y_\alpha = C ,$$

where m_α and σ_α^2 are the mean and the variance, respectively.

In order to solve equations (4.1), we choose a value of λ in the permissible range, compute the y_α's, and from their values determine the corresponding C. In practice, however, we are given C, not λ. We therefore repeat this calculation for several values of λ until we find a λ which corresponds to the given C. We are then ready to determine $u_\alpha(y_\alpha)$'s, namely the average amounts supplied. These can be written as:

$$u_\alpha(y_\alpha) = m_\alpha \left(1 - \lambda \frac{c_\alpha}{w_\alpha}\right) + y_\alpha \left[1 - \left(1 - \lambda \frac{c_\alpha}{w_\alpha}\right)\right] - \frac{\sigma_\alpha}{\sqrt{2\pi}} e^{-(y_\alpha - m_\alpha)^2/2\sigma_\alpha^2}$$

(4.2)

$$\alpha = 1, \ldots, n .$$

We shall be able to gain further insight into the meaning of these equations for y_α and $u_\alpha(y_\alpha)$ for the normal case if we assign definite numerical values to the parameters of these distributions and compute the resulting y_α and $u_\alpha(y_\alpha)$. Such a numerical model is presented in Table 1.1. It should be noted that the mean is taken to be rather large, since we are considering the normal distribution as the asymptotic form of some other distribution. It is only in this case (i.e., when $m_\alpha/\sigma_\alpha > 4$) that equations (4.1) and (4.2) are sufficiently accurate for our purposes.

TABLE 1.1

$$\sum_\alpha E(x_\alpha)\, c_\alpha = 2400$$

α	w_α	c_α	$E(x_\alpha) = m_\alpha$	$\sqrt{\mathrm{Var}(x_\alpha)} = \sigma_\alpha$
1	1	1	100	3
2	1	1	100	10
3	1	5	100	3
4	1	5	100	10
5	2	1	100	3
6	2	1	100	10
7	2	5	100	3
8	2	5	100	10

These numbers were picked so as to represent quantities with a wide range of combinations of cube, "weight," and variance. In order to acquire a feeling for the order of magnitude of a given C, one should compare it with $\sum_\alpha E(x_\alpha)\, c_\alpha$. This sum would be the C if one were to take y_α equal to the mean usage of commodity α, for all α. In Table 1.2 we list the results.

TABLE 1.2

α	$\lambda = 0.01$; $C = 2698.3$		$\lambda = 0.02$; $C = 2647.5$		$\lambda = 0.05$; $C = 2565.4$		$\lambda = 0.10$; $C = 2481.5$		$\lambda = 0.15$; $C = 2409.7$	
	y_α	$u_\alpha(y_\alpha)$	y_α	$u_\alpha(y_\alpha)$	y_α	$u_\alpha(y_\alpha)$	y_α	$u_\alpha(y_\alpha)$	y_α	$u_\alpha(y_\alpha)$
1	107.0	99.99	106.2	99.98	104.9	99.94	103.8	99.86	103.1	99.77
2	123.3	99.97	120.5	99.93	116.5	99.79	112.8	99.53	110.4	99.22
3	104.9	99.94	103.9	99.86	102.0	99.55	100.0	98.80	98.0	97.53
4	116.5	99.79	112.8	99.53	106.7	98.51	100.0	96.01	93.3	91.76
5	107.7	99.99	107.0	99.99	105.9	99.97	104.9	99.94	104.3	99.90
6	125.8	99.98	123.3	99.97	119.6	99.91	116.5	99.79	114.4	99.67
7	105.9	99.97	104.9	99.94	103.5	99.81	102.0	99.55	101.0	99.22
8	119.6	99.91	116.5	99.79	111.5	99.38	106.7	98.51	103.2	97.40

Because the $E(x_\alpha) = 100$ for all α in this example, $u_\alpha(y_\alpha)$ also is numerically equal to the percentage of demands met. This also holds for examples 2 and 3, with the exception of the first six cases of example 2. In that case, $E(x_\alpha) = 10$, and therefore $10u_\alpha(y_\alpha)$ is numerically equal to the percentage of demands met. We shall postpone the detailed interpretation of these numerical results to Section 5.

TABLE 1.3

C	W_0	$\frac{\Delta W_0}{\Delta C}$
2409.7	1180.7	
		0.127
2481.5	1189.8	
		0.0727
2565.4	1195.9	
		0.0341
2647.5	1198.7	
		0.0138
2698.3	1199.4	

Example 2 - The Logarithmic Normal Distribution

Let us consider the case where $\ln x_\alpha$ is normally distributed.[3] Then

$$\phi_\alpha(x_\alpha) = \frac{1}{\sqrt{2\pi}\,\sigma_\alpha x_\alpha} e^{-(\ln x_\alpha - m_\alpha)^2/2\sigma_\alpha^2},$$ where m_α and σ_α^2 are $E(\ln x_\alpha)$ and $\mathrm{Var}(\ln x_\alpha)$, respectively; and equations (3.1) become:

$$\frac{1}{\sqrt{2\pi}} \int_{-\infty}^{(\ln y_\alpha - m_\alpha)/\sigma_\alpha} e^{-\tau^2/2}\, d\tau = 1 - \lambda \frac{c_\alpha}{w_\alpha},$$

$$\sum_\alpha c_\alpha y_\alpha = C .$$

Also, $u_\alpha(y_\alpha)$, the total quantity of commodity α supplied on the average, is given by:

$$u_\alpha(y_\alpha) = E(x_\alpha) \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{(\ln y_\alpha - m_\alpha - \sigma_\alpha^2)/\sigma_\alpha} e^{-t^2/2}\, dt + y_\alpha \frac{1}{\sqrt{2\pi}} \int_{\frac{\ln y_\alpha - m_\alpha}{\sigma_\alpha}}^{\infty} e^{-t^2/2}\, dt ,$$

where
$$E(x_\alpha) = e^{m_\alpha + \sigma_\alpha^2/2}$$

[3]See, for example, A. Hald: Statistical Theory with Engineering Application, p. 160.

In Table 2.1 we shall illustrate this model by means of a numerical example. It should be noted that this numerical model differs from the one given in Table 1.1 in including cases with a much smaller mean. The results appear in Tables 2.2 and 2.3.

TABLE 2.1

$$\sum_{\alpha} E(x_\alpha)\, c_\alpha = 1980$$

α	w_α	c_α	$E(x_\alpha)$	$\sqrt{Var(x_\alpha)}$	m_α	σ_α
1	1	1	10	3	2.25949	.29359
2	1	1	10	10	1.95600	.83256
3	1	1	10	30	1.15129	1.51742
4	1	5	10	3	2.25949	.29359
5	1	5	10	10	1.95600	.83256
6	1	5	10	30	1.15129	1.51742
7	1	1	100	30	4.56208	.29359
8	1	1	100	100	4.25860	.83256
9	1	1	100	300	3.45388	1.51742
10	1	5	100	30	4.56208	.29359
11	1	5	100	100	4.25860	.83256
12	1	5	100	300	3.45388	1.51742

TABLE 2.2

α	$\lambda = 0.01$; C = 6261.18		$\lambda = 0.02$; C = 4522.98		$\lambda = 0.05$; C = 2706.96		$\lambda = 0.10$; C = 1712.63		$\lambda = 0.15$; C = 1318.47	
	y_α	$u_\alpha(y_\alpha)$	y_α	$u_\alpha(y_\alpha)$	y_α	$u_\alpha(y_\alpha)$	y_α	$u_\alpha(y_\alpha)$	y_α	$u_\alpha(y_\alpha)$
1	18.97	9.98	17.51	9.91	15.53	9.89	13.96	9.78	12.98	9.66
2	49.08	9.81	39.10	9.67	27.82	9.31	20.56	8.79	16.75	8.32
3	92.57	8.84	71.38	8.47	38.38	7.43	22.12	6.28	15.23	5.43
4	15.53	9.89	13.96	9.78	11.68	9.40	9.58	8.63	7.86	7.52
5	27.82	9.31	20.56	8.79	12.40	7.47	7.07	5.56	4.03	3.68
6	38.38	7.43	22.12	6.28	8.80	4.20	3.16	2.23	1.14	0.99
7	189.67	99.79	175.06	99.10	155.25	98.93	139.56	97.80	129.83	96.60
8	490.76	98.14	390.99	96.71	278.15	93.08	205.60	87.89	167.52	83.20
9	925.70	88.44	713.80	84.69	383.77	74.26	221.23	62.80	152.31	54.37
10	155.25	98.93	139.56	97.80	116.76	94.03	95.78	86.34	78.57	75.25
11	278.15	93.08	205.60	87.89	123.98	74.71	70.71	55.61	40.33	36.84
12	383.77	74.26	221.23	62.80	88.00	41.96	31.62	22.27	11.36	9.93

TABLE 2.3

C	W_0	$\frac{\Delta W_0}{\Delta C}$
1318.5	391.79	
		0.19
1712.6	453.98	
		0.071
2707.0	524.67	
		0.032
4523.0	581.89	
		0.015
6261.2	607.90	

Example 3 - The Case of Several Distributions

In this model some of the $\phi_\alpha(x_\alpha)$ are normally distributed, while others have the logarithmic normal distribution. In Table 3.1, the first 6 cases have the logarithmic normal distribution and the last 4 the normal. y_α, and $u_\alpha(y_\alpha)$ are computed as in Example 1 for $\alpha = 1, \ldots, 6$ and as in Example 2 for $\alpha = 7, \ldots, 10$. The results are tabulated in Tables 3.2 and 3.3.

TABLE 3.1

$$\sum_\alpha E(x_\alpha)\, c_\alpha = 3000$$

α	W_α	c_α	$E(x_\alpha)$	$\sqrt{\operatorname{Var}(x_\alpha)}$	m_α	σ_α
1	1	1	100	3	4.60472	0.03000
2	1	1	100	10	4.60020	0.09994
3	1	1	100	30	4.56208	0.29359
4	1	5	100	3	4.60472	0.03000
5	1	5	100	10	4.60020	0.09994
6	1	5	100	30	4.56208	0.29359
7	1	1	100	3	100	3
8	1	1	100	10	100	10
9	1	5	100	3	100	3
10	1	5	100	10	100	10

TABLE 3.2

α	$\lambda = 0.01$; C = 3647.30		$\lambda = 0.02$; C = 3496.25		$\lambda = 0.05$; C = 3268.53		$\lambda = 0.10$; C = 3049.40		$\lambda = 0.15$; C = 2860.67	
	y_α	$u_\alpha(y_\alpha)$	y_α	$u_\alpha(y_\alpha)$	y_α	$u_\alpha(y_\alpha)$	y_α	$u_\alpha(y_\alpha)$	y_α	$u_\alpha(y_\alpha)$
1	107.1[illegible]	[illegible]9.99	106.31	99.98	105.01	99.93	103.87	99.85	103.11	99.76
2	125.56	99.96	122.18	99.91	117.28	99.75	113.11	99.44	110.36	99.13
3	189.66	99.79	175.06	99.58	155.25	98.93	139.55	98.04	129.83	96.59
4	105.01	99.93	103.87	99.85	102.00	99.54	99.96	98.78	97.95	99.41
5	117.28	99.75	113.11	99.44	106.39	98.32	99.50	95.82	93.02	91.70
6	155.25	98.93	139.55	98.04	116.76	94.02	95.78	86.34	78.57	75.58
7	106.98	99.99	106.16	99.98	104.94	99.94	103.85	99.86	103.11	99.77
8	123.27	99.97	120.54	99.93	116.45	99.79	112.82	99.53	110.36	99.22
9	104.94	99.94	103.85	99.86	102.02	99.55	100.00	98.80	97.98	97.53
10	116.45	99.79	112.82	99.53	106.75	98.51	100.00	96.01	93.26	91.76

TABLE 3.3

C	W_0	$\frac{\Delta W_0}{\Delta C}$
2860.67	950.5	
		.117
3049.40	972.5	
		.0721
3268.53	988.3	
		.0343
3496.25	996.1	
		.0192
3647.30	999.0	

5. DISCUSSION

Some fairly general rules can be gleaned from a scrutiny of these tables. It becomes clear for the normal case that commodities with a large variance are stocked to a considerable degree in a large vessel, but only very sparingly when the available space is rather limited. In fact, when the space becomes very hard to get, one stocks considerably less than the amount equal to the mean usage for those commodities which have wide fluctuations of demand. In Appendix I we show that a modified version of this rule has a rather wide range of applicability. We show also that for many distributions, when the mean is multiplied by k and the variance by k^2, then y_α and $u_\alpha(y_\alpha)$ also are multiplied by k. This also is noticeable in the numerical model (see Table 2.2). It also can be seen that commodities with large cube must be stocked sparingly in a small vessel. These results are true for a wide class of distributions. The specific numerical values of the y_α's and the $u_\alpha(y_\alpha)$'s are, of course, more sensitive to the particular distribution and may have to be computed for each individual case.

The very fact that the general rules which come out of our model are eminently plausible serves as an a posteriori justification of the basic assumptions we have made in the Introduction.

We come now to the discussion of the behavior of the maximum utility function, W_0. We note that as C (total available cube) is increased, W_0 at first rises sharply, but then its rate of increase diminishes. This becomes especially clear when one examines the behavior of the ratio $\Delta W_0/\Delta C$. The behavior of W_0 can be used as a guide in deciding on the amount of space C to be set aside on a given ship for storage of commodities.

From the above discussion it appears that the present model leads to reasonable results for commodities of a noncritical nature. It might, therefore, be used as a basis for some preliminary allowance list computations.

It is clear, of course, that our criterion of maximizing the average number of fulfilled demands may not be the only useful criterion. For example, one might use the criterion that the sum of the mean square deviations of the demands from the amounts stocked shall be a minimum, subject to the space constraint. In other words, we could minimize

$$E\left[\sum_\alpha (x_\alpha - y_\alpha)^2\right] = \sum_\alpha \int_0^\infty (x_\alpha - y_\alpha)^2 \phi_\alpha(x_\alpha)\, dx_\alpha$$

$$= \sum_\alpha \left\{\mathrm{Var}(x_\alpha) + [E(x_\alpha) - y_\alpha]^2\right\}$$

subject to $\sum_\alpha c_\alpha y_\alpha = C$.

This would yield the relations

$$y_\alpha = E(x_\alpha) + c_\alpha \left[\frac{C - \sum_{\beta=1}^{n} c_\beta E(x_\beta)}{\sum_{\beta=1}^{n} c_\beta^2}\right] \quad \text{for } \alpha = 1, \ldots, n .$$

Because this model minimizes the mean square deviation of the demand from the amount stocked, it could be expected to lead to overemphasis on meeting the demands of commodities with very large variance at the expense of those commodities whose demand is reasonably uniform. Our model, on the other hand, does not minimize this mean squared deviation, but concentrates instead on meeting the greatest possible number of demands on the average. Thus, it appears that the criterion that we have chosen, while not unique, does lead to desirable consequences.

The model that we have considered in this paper is a purely probabilistic one. We have assumed that the probability density functions were known. In practice, the probability distribution is not known, and only some of its properties can be obtained from the analysis of the available data. One can use this statistical information in order to determine the parameters in an appropriately chosen distribution function. This, in fact, is the way in which one must use the present model for detailed computations. On the other hand, one could conceivably

reformulate the problem so as to take more direct advantage of the available information, possibly bypassing some of the intermediate steps inherent in the present formulation.

APPENDIX I

The General Theory

Let us define the following set of functions

$$f_\alpha (x_\alpha , y_\alpha) = \begin{cases} w_\alpha x_\alpha & \text{when } x_\alpha \le y_\alpha \\ w_\alpha y_\alpha & \text{when } x_\alpha \ge y_\alpha \end{cases}, \quad \alpha = 1, \ldots , n ,$$

where x_α is the amount of commodity α demanded, and y_α is the amount of commodity α stocked, and where w_α are the relative weights assigned the commodities according to their importance. This function, $f_\alpha (x_\alpha, y_\alpha)$, represents the "gain" that we achieve if we meet a demand x_α when we stock an amount y_α. Of course, when x_α is larger than y_α, we meet the demand as best we can, namely, by supplying what we have in stock y_α.

Our objective is to maximize our total gain. We approach this by maximizing the total utility function, W (defined as the expected value of the total gain), subject to the space constraint. In other words, we maximize

$$W (y_1, \ldots , y_n) = E\left[\sum_{\alpha=1}^{n} f_\alpha (x_\alpha, y_\alpha)\right] \text{ subject to } \sum_\alpha c_\alpha y_\alpha = C .$$

It should be noted that we have assumed the gain to be additive. Now,

$$E\left[\sum_\alpha f_\alpha (x_\alpha, y_\alpha)\right] = \int \cdots \int \sum_\alpha f_\alpha (x_\alpha, y_\alpha)\, \Phi (x_1, \ldots , x_n)\, dx_1, \ldots dx_n ,$$

where $\Phi (x_1, \ldots , x_n)$ is the joint probability density function of $x_1, \ldots , x_n$.

We have made the assumption that the demand for commodity α is independent of commodity β, so that their joint probability density function can be written as:

$$\Phi (x_1, \ldots , x_n) = \phi_1 (x_1)\phi_2 (x_2) \ldots \phi_n (x_n) ,$$

where $\phi_\alpha(x_\alpha)$ is the probability density function of x_α. The range of each x_α clearly is from 0 to ∞. Whenever no limits of integration are indicated, they are to be taken as from 0 to ∞.

Since
$$\int \phi_\alpha (x_\alpha)\, dx_\alpha = 1 ,$$
we get:
$$E\left[\sum_\alpha f_\alpha (x_\alpha , y_\alpha)\right] = \int f_1 (x_1 , y_1)\phi_1 (x_1)\, dx_1 + \ldots + \int f_n (x_n , y_n)\phi_n (x_n)\, dx_n .$$

Now let us define

$$w_\alpha u_\alpha (y_\alpha) = E f_\alpha (x_\alpha , y_\alpha) = \int f_\alpha (x_\alpha , y_\alpha)\phi_\alpha (x_\alpha)\, dx_\alpha$$

and therefore maximize

$$W (y_1 , \ldots , y_n) = \sum_\alpha w_\alpha u_\alpha (y_\alpha) \text{ subject to } \sum_\alpha c_\alpha y_\alpha = C .$$

Using the method of Lagrange multipliers, we form the function

$$D = \sum_\alpha w_\alpha u_\alpha (y_\alpha) - \lambda \left[\sum_\alpha c_\alpha y_\alpha - C\right] .$$

We get n equations of the form:

(I.1)
$$0 = \frac{\partial D}{\partial y_\alpha} = \frac{d}{d y_\alpha} [w_\alpha u_\alpha (y_\alpha)] - \lambda c_\alpha .$$

The set of equations (I.1), together with the equation of constraint, determines the $n + 1$ variables y_α and λ . Equations (I.1) can be written as:

$$\lambda \frac{c_\alpha}{w_\alpha} = \frac{d}{d y_\alpha} u_\alpha (y_\alpha)$$

$$= \frac{d}{d y_\alpha}\left[\int_0^{y_\alpha} x_\alpha \phi_\alpha (x_\alpha)\, dx_\alpha + y_\alpha \int_{y_\alpha}^{\infty} \phi_\alpha (x_\alpha)\, dx_\alpha\right]$$

$$= \int_{y_\alpha}^{\infty} \phi_\alpha (x_\alpha)\, dx_\alpha .$$

Remembering the normalization of the $\phi_\alpha (x_\alpha)$, we have the final form of our equations:

(I.2)
$$\int_0^{y_\alpha} \phi_\alpha (x_\alpha)\, dx_\alpha = 1 - \lambda \frac{c_\alpha}{w_\alpha}$$

and
$$\sum_\alpha c_\alpha y_\alpha = C .$$

These equations determine a unique set of y_α's, provided that, for all α, $\phi_\alpha (x_\alpha) > 0$ for all values of x_α (except possibly on a set of measure zero).

That this stationary point is really a maximum of $W(y_1, \ldots, y_n)$ can be easily shown by the methods outlined in Courant-Hilbert, "Methoden der Mathematischen Physik," 1931 edition, p. 200.

We are now ready to compute the mean quantity of commodity α supplied when an amount y_α is stocked. This is obtained as follows: If an amount of x_α is demanded which is less than y_α, then that amount is supplied. If, on the other hand, the amount demanded, x_α, is larger than the amount stocked, only an amount y_α can be supplied. Thus the average amount supplied is:

$$u_\alpha(y_\alpha) = \int_0^{y_\alpha} x_\alpha \phi_\alpha(x_\alpha)\, dx_\alpha + \int_{y_\alpha}^{\infty} y_\alpha \phi_\alpha(x_\alpha)\, dx_\alpha .$$

The mean quantity of commodity α not supplied when an amount y_α is stocked is:

$$v_\alpha(y_\alpha) = \int_{y_\alpha}^{\infty} (x_\alpha - y_\alpha)\phi_\alpha(x_\alpha)\, dx_\alpha .$$

Clearly,

$$u_\alpha(y_\alpha) + v_\alpha(y_\alpha) = E(x_\alpha)$$

where

$$E(x_\alpha) = \int x_\alpha \phi_\alpha(x_\alpha)\, dx_\alpha .$$

In order to solve equations (I.2), we shall assume a value of λ; compute y_α by using a table of the appropriate cumulative distribution function; and then determine the corresponding C from the subsidiary condition. Since,

$$0 \leq \int_0^{y_\alpha} \phi_\alpha(x_\alpha)\, dx_\alpha \leq 1 ,$$

it follows that $\dfrac{w_\alpha}{c_\alpha} \geq \lambda \geq 0$ for all α, and therefore $\min\left(\dfrac{w_\alpha}{c_\alpha}\right) \geq \lambda \geq 0$. This defines the range of permissible values of λ.

We shall now turn to the discussion of several useful properties of our model. We shall show that if the mean is multiplied by k and the variance by k^2, then y_α and $u_\alpha(y_\alpha)$ also are multiplied by k. This is usually true for distributions which have more than one parameter. For example, it holds for the normal and the logarithmic normal but does not hold for the Poisson. The proof proceeds as follows (for simplicity we delete the subscript α):

Given a distribution function $\phi(x)$, such that

$$(1) \quad \int \phi(x)\, dx = 1$$

$$(2) \quad E(x) = \int x\phi(x)\, dx = M$$

and

$$(3) \quad \mathrm{Var}(x) = \int x^2 \phi(x)\, dx - [E(x)]^2 = \Sigma^2 ,$$

then the distribution function

$$\psi(x) = \frac{1}{k}\phi\left(\frac{x}{k}\right), \qquad k > 0$$

has the properties:

$$(1) \quad \int \psi(x)\,dx = \int \frac{1}{k}\phi\left(\frac{x}{k}\right)dx = \int \phi(z)\,dz = 1$$

$$(2) \quad E(x) = \int x\,\psi(x)\,dx = \int x\,\frac{1}{k}\phi\left(\frac{x}{k}\right)dx$$

$$= k\int 2\,\phi(2)\,dz = kM$$

and

$$(3) \quad \mathrm{Var}\,(x) = \int x^2\psi(x)\,dx - [E(x)]^2 = \int x^2\,\frac{1}{k}\phi\left(\frac{x}{k}\right)dx - [E(x)]^2$$

$$= k^2\int z^2\phi(z)\,dz - [kM]^2 = k^2\,\Sigma^2 .$$

If the distribution function $\psi(x)$ has the same analytical form as $\phi(x)$, differing from it only in the values of its parameters, then we can use it to find the scaling laws for y and $u(y)$. Thus, if y is defined by the equation

$$\int_0^y \phi(x)\,dx = 1 - \lambda\frac{c}{w},$$

then

$$1 - \lambda\frac{c}{w} = \int_0^{y'} \psi(x)\,dx = \int_0^{y'} \frac{1}{k}\phi\left(\frac{x}{k}\right)dx = \int_0^{y'/k} \phi(z)\,dz,$$

and therefore

$$y' = ky .$$

This defines the new amounts to be stocked. Also, if originally

$$u(y) = \int_0^y x\phi(x)\,dx + y\int_y^{\infty} \phi(x)\,dx .$$

Now,

$$u'(y') = \int_0^{y'} x\psi(x)\,dx + y'\int_{y'}^{\infty} \psi(x)\,dx,$$

$$= \int_0^{y'} x\,\frac{1}{k}\phi\left(\frac{x}{k}\right)dx + y'\int_{y'}^{\infty} \frac{1}{k}\phi\left(\frac{x}{k}\right)dx,$$

$$u'\,y' = k\int_0^{y'/k} z\phi(z)\,dz + y'\int_{y'/k}^{\infty} \phi(z)\,dz = ku(y) .$$

It also is easy to show another fairly general property of the model. If a function $g(x)$ of the variable x is normally distributed, with mean m and variance σ^2, then

$$\xi = \frac{g(x) - m}{\sigma}$$

is $N(0, 1)$. Then,

$$\phi(x) = \frac{1}{\sqrt{2\pi}\sigma} e^{-(g(x)-m)^2/2\sigma^2} \frac{dg(x)}{dx}.$$

We shall consider the case where $g(x)$ is a monotonically increasing function of x such that $-\infty < g(x) < \infty$, while $0 \leq x < \infty$. Then

$$\int_0^y \phi(x)\, dx = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{(g(y)-m)/\sigma} e^{-\xi^2/2}\, d\xi = 1 - \lambda \frac{c}{w}.$$

Clearly, whenever $1 - \lambda \frac{c}{w} = \frac{1}{2}$ we have $g(y) = m$, which can be solved for y. If $1 - \lambda \frac{c}{w} > \frac{1}{2}$, then $\frac{g(y - m)}{\sigma} = \tau > 0$, and therefore $g(y) = m + \tau\sigma$. Clearly τ is the same for two commodities having equal $\frac{c}{w}$, even though their means and variances may differ. But if $\tau_1 = \tau_2$, $m_1 = m_2$, and $\sigma_1 > \sigma_2$, then clearly $g_1(y_1) > g_2(y_2)$, and therefore also $y_1 > y_2$. Similarly, if $1 - \lambda \frac{c}{w} < \frac{1}{2}$, $\frac{g(y) - m}{\sigma} = -\tau < 0$; and if $\tau_1 = \tau_2$, $m_1 = m_2$, and $\sigma_1 > \sigma_2$, then $g_1(y_1) < g_2(y_2)$ and $y_1 < y_2$. This shows that for small C (large positive λ) one stocks less of the commodities with large σ. On the other hand, when C is large, one stocks more of the commodities with large σ than of those with small σ.

* * *

The George Washington University

LOGISTICS RESEARCH PROJECT

Contract Nonr761

Task 03, Project NR 345 107
Task 05, Project NR 047 001
Task 06, Project NR 347 008

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POLARIS LOGISTICS STUDIES
Number 3

A POLARIS LOGISTICS MODEL

MARVIN DENICOFF
JOSEPH FENNELL
SHELDON E. HABER
W. H. MARLOW
HENRY SOLOMON

Serial T-162
26 August 1963

THE GEORGE WASHINGTON UNIVERSITY
LOGISTICS RESEARCH PROJECT

Contract Nonr761
Task 03, Project NR 345 107
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Office of Naval Research

THE GEORGE WASHINGTON UNIVERSITY
Logistics Research Project

Abstract
of
Serial T-162

A POLARIS LOGISTICS MODEL

MARVIN DENICOFF
JOSEPH FENNELL
SHELDON E. HABER
W. H. MARLOW
HENRY SOLOMON

This paper presents a basic loss minimization model which has been applied in varying contexts for Polaris logistics problems. Definitive results are obtained in a general framework which extends the classic newsboy problem in two principal directions. First, probability distributions for demand are unrestricted. Second, a general framework for "penalties" or "premiums" is introduced to permit formulation of possibly non-convex loss functions. The main result is a constructive existence theorem for minimum values of these general expected loss functions.

PREFACE

The present study is the third of several papers to be issued by this Project as Polaris Logistics Studies. Subsequent papers will consider allowance list determinations, FBM load lists for deployed tenders, ashore supply point problems, provisioning and procurement policies, and finally the general problem of providing logistics information and control systems to permit overall satisfactory logistics.

It will become apparent that the present series will represent a somewhat diverse range of interests. In addition to the fact that a somewhat heterogeneous set of research techniques will appear there is one feature which deserves special comment. This refers to the fact that careful attention is given to the underlying situations to which the methodology is to apply. It turns out that this introduces the need for considerable precision of terminology in engineering and logistics areas which unfortunately include areas notorious for their lack of standards, e.g., the problem of definition of a "component" as opposed to an "equipment". Nevertheless, a substantial part of the contribution of the present series is judged to consist of its relevance for practical problems: this has required that unswerving attention be paid to the exigencies of the background situations and their definitions.

It is a pleasure to acknowledge the support of the Logistics and Mathematical Statistics Branch of the Office of Naval Research under whose contracts this work has been performed. In just the same way, appreciation is due the Technical Director, Special Projects Office, and his Assistant for Material Support who are co-sponsors of this research by means of transfer of necessary funds to the Office of Naval Research. Mention should also be made of the fact that the Bureau of Supplies and Accounts and its field activities have been collaborators in the present studies. Finally, it is most appropriate to cite the essential assistance and support provided by the Logistics Research Project administrative and clerical staff and by the members of the Project Computation Laboratory who were essential for this work.

W. H. Marlow

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A POLARIS LOGISTICS MODEL[1]

Marvin Denicoff[2]
Joseph Fennell
Sheldon E. Haber
W. H. Marlow
Henry Solomon

0. Introduction.

The aim of this paper is to present the foundation for a family of logistics models which can be used to formulate and solve a variety of problems. Each member of the family results as a special case of a single basic loss minimization model. It is to this basic underlying model that the present paper mainly applies. Subsequent papers in the Polaris Logistics Studies series will discuss applications in detail, particularly in the areas of allowance lists and load lists. Terminology and notation are consistent with earlier studies in the present series [1, 2] wherein will be found considerable

[1] The preparation of this paper was sponsored by the Office of Naval Research and the Special Projects Office. Reproduction in whole or in part is permitted for any purpose of the United States Government.

[2] Navy Bureau of Supplies and Accounts

additional background material affecting applications.

1. Basic expectations.

Our loss minimization model is a generalization of the formulation for the classic "newsboy problem" which dates back at least to World War II [3, pages 31 - 32]. This is the problem of the boy who is required to buy his papers at 2 cents and sell them at 3 cents, and is not allowed to return his unsold papers. Under conditions permitting the assumption that his customers appear according to a Poisson distribution with known mean, say 10, it turns out that expected profit will be maximum (i.e., loss will be minimum) if he buys 9 papers rather than the obvious quantity 10. So far as we know, earliest publication of a generalized version of such a model was [4]; Whitin and Youngs also seem to have been the first to state that the assumption of Poisson distribution of demand is inessential. Our present development is distinguished principally by two features.

a. A generalized loss function is employed which includes the formulation of [4] as a non-trivial special case.

b. No special conditions are imposed on the distribution of demand which may be any probability distribution with a finite mean.

It will be convenient to phrase our exposition in terms of a submarine allowance list problem. Afterwards, we will consider wider application for our results but for now we limit our attention for illustration. We consider a specific allowance list candidate which is a particular repair part competitor for placement on-board for use by ships force in direct support of installed components. (See [2, page 30].) It is correct to regard such a part as one which may possibly be required

for use during patrol, i.e., at a time when the vessel will be operating in isolation with no possibility whatsoever of obtaining repair parts from sources other than its own allowance list stocks. For the specific item we are considering we require that two real numbers be specified relative to a single patrol period.

(1.1)

A = penalty per unit stocked in excess of number demanded during the entire patrol.

B = penalty per unit demanded in excess of number stocked for the entire patrol.

Different repair parts candidates may have different (A, B) pairs assigned subject to the following requirements of which the first serves only to eliminate complete triviality.

(1.2) Not both of A and B are zero.

(1.3) Both A and B are expressed as values on a common numerical scale which is furthermore common to all allowance list candidates.

The common numerical scale in (1.3) is the measuring scale for utility which will underlie our work. Our objective will be to minimize total expected penalties associated with values accrued on this scale. We may as well imagine that the scale in (1.3) is as large as the entire real number system: positive numbers represent penalties while negative numbers denote premiums. As noted above, we aim to minimize loss or, what is the very same thing, to maximize gain.

It is clear that the most advantageous <u>allowance quantity</u>, n, would equal exactly d, the quantity to be demanded for use during

patrol. If such were possible, i.e., if $n = d$, a minimum loss of zero would accrue. If $n > d$ a loss would be incurred due to there being a surplus; specifically, we would lose $(n - d)A$. On the other hand, with $n < d$ there would be a shortage of $(d - n)$ units with associated penalty $(d - n)B$. In the absence of advance knowledge as to the value to be assumed by d we turn to a probability distribution to be able to treat future uncertain demands. That is, for the specific candidate we are considering, there must be defined

(1.4) P_i = Probability of exactly i units being demanded for use during patrol: $i = 0, 1, 2, \ldots$.

This requires

$$P_i \geqq 0 \text{ for each } i \text{ and } \sum_{i=0}^{\infty} P_i = 1 . \tag{1.5}$$

It will be a notational convenience to write

$$C_s = \sum_{i=0}^{s} P_i \tag{1.6}$$

to denote a cumulative probability. In the present context C_s represents the probability that demand during a patrol will not exceed s units of the item we are considering as an allowance list candidate. We will write m to denote the mean[1] of the distribution (1.4), i.e., the expected number of units demanded,

$$m = \sum_{i=0}^{\infty} i\, P_i . \tag{1.7}$$

---

[1] In the following we suppose that the mean m exists as a finite quantity in order to avoid unrewarding complications.

Given the distribution (1.4) we define the surplus function, a, whose value $a(s)$, $s = 0, 1, 2, \ldots$, equals the expected number of units overstocked during a patrol in case the allowance quantity equals s. We readily compute

$$a(s) = \sum_{i=0}^{s} (s - i) P_i . \tag{1.8}$$

We proceed in analogous fashion to define a shortage function, b, whose value $b(s)$, $s = 0, 1, 2, \ldots$, equals the expected number of units understocked during a patrol in case the allowance quantity equals s. We find

$$b(s) = \sum_{i=s+1}^{\infty} (i - s) P_i . \tag{1.9}$$

This completes the set of functions we need in order to formulate loss functions for minimization.

It will be convenient to have available some standard mathematical terminology applicable to a function α defined on integers.

> DEFINITION. A function α defined on $s = 0, 1, 2, \ldots$ is said to be nondecreasing if $s_1 < s_2$ implies $\alpha(s_1) \leqq \alpha(s_2)$. In case the strict inequality always holds then α is an increasing function. The terms non-increasing and decreasing have corresponding definitions.

Functions falling into one of the above categories are termed monotonic functions. Next, we require the definition of a convex function. For the case of a curve α, convexity means that if a chord is drawn between two points on the curve then no point on the chord can lie below the curve.

DEFINITION. A function α defined on $s = 0, 1, 2, \ldots$ is said to be convex in s if

$$2\,\alpha(s) \leqq \alpha(s-1) + \alpha(s+1) \tag{1.10}$$

holds for $s = 1, 2, \ldots$. In case the strict inequality always holds then α is strictly convex. The function α is called concave in case $-\alpha$ is convex; there is the corresponding definition for strictly concave.

Condition (1.10) simply requires that the second differences be nonnegative. A convenient equivalent rearrangement of (1.10) requires that the first differences be nondecreasing:

$$\alpha(s) - \alpha(s-1) \leqq \alpha(s+1) - \alpha(s) \; . \tag{1.11}$$

This exhibits convexity as a property of diminishing returns. Indeed, if

$$\Delta\,\alpha(s) = \alpha(s+1) - \alpha(s)$$

represents the difference in return going from "state" s to $s+1$, then if α is convex,

$$\Delta\,\alpha(s-1) \leqq \Delta\alpha(s) \leqq \Delta\alpha(s+1) \leqq \ldots \quad \text{etc.}$$

One of the most important properties of a convex function is that it possesses at most one local minimum, i.e., any minima are "gl obal". Specifically, if

$$\alpha(s'-1) \geqq \alpha(s') \leqq \alpha(s'+1)$$

then there can be no integer s for which $\alpha(s) < \alpha(s')$. This conclusion is a consequence of the fact that (1.11) in this case

causes $\alpha(s) \geqq \alpha(s')$ for $s < s'$ and also for $s > s'$. Of course a convex function need not have any minimum at all, e.g., $\alpha(s) = -s$ for $s = 0, 1, 2, \ldots$, or more generally, in case $\Delta\alpha$ is negative for all s. However, if $\Delta\alpha(s^*) \geqq 0$ for at least one s^*, then there is a unique smallest s, $0 \leqq s \leqq s^*$, at which $\Delta\alpha(s) \geqq 0$. For this first (perhaps the only) s, $\Delta\alpha(s)$ changes sign assuring that $\alpha(s)$ is a global minimum. In what follows we shall make considerable use of this last mentioned property Specifically, we shall find the smallest integer s by successively testing the sign of $\Delta\alpha(s)$ in the order $s = 0, 1, 2, \ldots$ to find the first s for which $\Delta\alpha(s) \geqq 0$.

We now return to consideration of the particular functions a and b, the surplus function (1.8) and the shortage function (1.9), respectively.

> LEMMA 1. The functions a and b are non-negative and convex in s. Furthermore, a is nondecreasing while b is nonincreasing.

PROOF. Non-negativity is an immediate consequence of the fact that $a(s)$ and $b(s)$ are both sums of non-negative numbers. Actually, the entire lemma follows readily with the aid of easily established expressions.

$$a(0) = 0 \tag{1.12}$$
$$a(s+1) = a(s) + C_s$$

$$b(0) = m \tag{1.13}$$
$$b(s+1) = b(s) - (1 - C_s)$$

For example, convexity of $a(s)$ is established by two applications of (1.12) whereby (1.10) is verified with

$$2a(s) = a(s-1) + a(s+1) - P_s .$$

Proof that $a(s)$ is nondecreasing is direct with (1.12) . Corresponding applications of (1.13) for $b(s)$ complete the proof. Notice that we cannot establish strict properties for all s (positivity, convexity or, e.g., that $a(s)$ be increasing) on account of possibly vanishing terms P_i . As an additional remark in passing we note that the following useful alternative expressions may readily be derived for the functions a and b .

(1.14) $$a(s) - b(s) = s - m$$

(1.15) $$a(s) = \sum_{j=0}^{s-1} \sum_{i=0}^{j} P_i = \sum_{j=0}^{s-1} C_j$$

(1.16) $$b(s) = m - \sum_{j=0}^{s-1} \sum_{i=j+1}^{\infty} P_i = m - \sum_{j=0}^{s-1} (1 - C_j)$$

A graphical illustration of the lemma is contained in Figure 1. Observe that $b(s)$ tends to zero as consistent with the expectation that average numbers of units "short" will diminish toward zero as s grows larger. On the other hand, $a(s)$ eventually climbs at an angle of 45° reflecting the expectation that from some point onward each additional unit stocked is likely to be a surplus item. It is important to notice that these expectations are in direct conflict: with loss expressed purely in terms of expected numbers of inventory units, moving so as to decrease loss $a(s)$ tends to increase loss $b(s)$, and conversely.

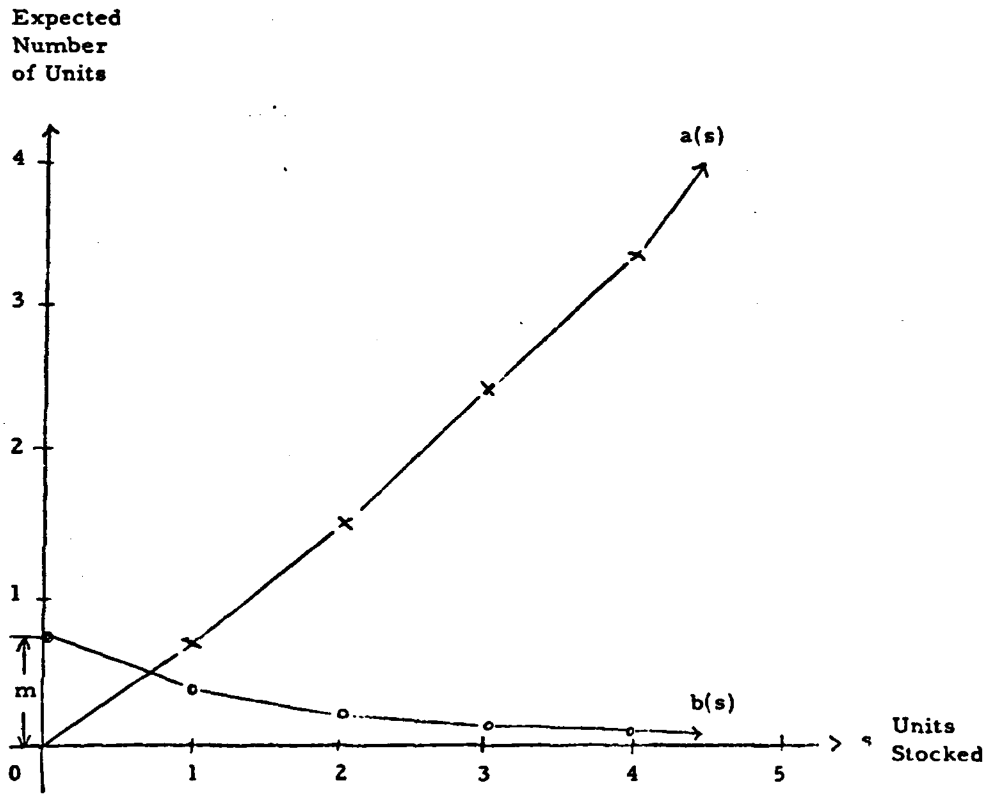

Figure 1. Graphs of $a(s)$ and $b(s)$.

2. Loss functions.

In the present paper we devote attention to a single general loss function. However, on account of the generality we are able to specialize in several interesting directions which explains our use of the plural form in the present section title. Let us consider a single allowance list candidate for which the demand distribution (1.4) and the penalties A and B of (1.1) are fixed. Then one possibility is to follow the lead of the classic newsboy and, as was done in [4], specify that the expected loss in case the allowance quantity is s will equal

$$a(s)\,A + b(s)\,B\,. \tag{2.1}$$

Such a procedure is entirely consistent with strict interpretation of (1.1) in which each and every surplus unit leads to a penalty of A and each and every unit short leads to a penalty of B. We could generalize this approach many ways: A and B could themselves be functions of s to reflect, say economic, considerations; we could employ quadratic functions of $a(s)$ and $b(s)$ rather than the linear (2.1); etc. Rather than pursuing such possibilities in the abstract, our present attention will be given to modifying (2.1) so as to reflect certain differences between the newsboy problem and others, notably submarine allowance list problems.

At the focal point of our concern is the number B in (1.1). In particular, we wish to be able to limit the number of times we could incur a unit penalty B. This is different than for the case of the newsboy for whom B equals one cent so that each and every unfilled demand gives rise to a penny loss. For the submarine, B by definition represents the penalty associated with each unit short of the repair part. Each such shortage will be considered to have a definite effect on its parent "component". Thus, for the submarine allowance list problem we let B measure the effect on the parent component

due to the shortage of a single repair part unit. This effect may be total loss of the function provided by the component or it could simply be "mild degradation". Whatever the effect on the component, B must represent it through providing a unit penalty measure. It is worth noting again at this point that B may vary in value from one repair part to another. In addition, we will now allow for variation of a different sort from candidate to candidate.

> DEFINITION. Associated with each candidate for stocking is a quantity σ called its span which is either a positive integer or else $\sigma = \infty$.

In case σ is finite then the largest possible penalty due to parts shortages will equal σB. We will associate the probability $\sum_{i=s+\sigma}^{\infty} P_i$ with accruing the maximum penalty σB when s units are stocked. This then means that we have an identical penalty σB associated with shortages equal to any one of $\sigma, \sigma + 1, \sigma + 2, \ldots$. In the contrary case, $\sigma = \infty$ causes iB to be associated with i units short no matter how large i may be. This latter procedure seems not unreasonable for the newsboy who sees, as we noted above, a penny loss for each and every unfilled demand. On the other hand, consider say Sonar Alfa which is installed in total number σ on board a submarine. If the submariner uses B for unit loss of one of these sonars then he could reason that σB is his maximum loss. Somewhat differently, Transistor Bravo might be installed σ times within the sonar while B represents a unit shortage of one transistor for this one sonar; again there is a rationale for span σ. Possibilities such as the above for the newsboy, for the submariner, and for others, are covered in the following loss function.

<u>DEFINITION</u>. The expected loss corresponding to stocking a quantity s for a candidate with span σ is as follows for $s = 0, 1, 2, \ldots$.

$$(2.2) \qquad L(s, \sigma) = \sum_{i=0}^{s} \{(s-i)A\} P_i + \sum_{i=s+1}^{s+\sigma} \{(i-s)B\} P_i + \sum_{i=s+\sigma+1}^{\infty} \{\sigma B\} P_i$$

We observe first that $L(s, \infty)$ is the limiting case of (2.2) with value as shown in (2.1) . More generally, (2.2) may be replaced by

$$(2.3) \qquad L(s, \sigma) = a(s) A + \{b(s) - b(s + \sigma)\} B$$

as may readily be verified with (1.9) .

<u>LEMMA 2</u>. Let $A \geqq 0$ and $B \geqq 0$ for definiteness. Then L is <u>non-negative</u> and, for any σ , is <u>convex</u> in s if and only if for all s

$$(2.4) \qquad (A + B) P_s - B P_{s+\sigma} \geqq 0 .$$

For any s , L is <u>concave and non-decreasing</u> in σ .

<u>PROOF</u>. The present lemma can be established along direct lines from Lemma 1. First, we may employ (1.12) and (1.13) together with (2.3) to write down several relations.

$$(2.5) \qquad L(0, \sigma) = \{m - b(\sigma)\} B$$

$$(2.6) \qquad L(s + 1, \sigma) = L(s, \sigma) + (A + B) C_s - B C_{s+\sigma}$$

$$(2.7) \qquad L(s, \sigma + 1) = L(s, \sigma) + B (1 - C_{s+\sigma})$$

Two applications of (2.6) directed toward (1.10) yield condition (2.4) while the final sentence in Lemma 2 of course results from (2.7).

COROLLARY. Let $A \geqq 0$ and $B \geqq 0$ for definiteness. Then if $\sigma = \infty$, L is convex in s.

PROOF. Condition (2.4) in this case is always satisfied in the form $(A + B) P_s \geqq 0$ which obtains since $P_{s+\sigma} = 0$ in the limit.

As we indicated in the paragraph following (1.10), convex functions are noteworthy for the relative ease by which their minima may be found. In particular, if L is not convex we must proceed with care to avoid mistaking a local minimum for a desired minimum for all s. Since we are permitting the probability distribution $\{P_i\}$ to be completely arbitrary, (2.4) may easily fail for finite σ: e.g., $P_s = 0$ and $P_{s+\sigma} > 0$ is clearly sufficient and there is nothing to prevent this occurring for an infinite number of integers s. However, it will turn out that despite possible non-convexity of L we will be able to minimize $L(s, \sigma)$ as a function of s without restrictive assumptions on $\{P_i\}$, A, B, or σ. All of this will come about through exploitation of Lemma 2 and its corollary.

3. Minimizing expected losses.

In this section we solve the problem of determining the most advantageous allowance quantity for our submarine allowance list example. In fact, we establish quite a bit more than this due to the generality of our formulation. The general problem to be solved consists of minimizing $L(s, \sigma)$ from (2.2) as a function of s for arbitrary $\{P_i\}$, A, B, and σ. It will be convenient to start with $\sigma = \infty$ which, as we have noted, corresponds to the classic newsboy problem.

<u>LEMMA 3</u>. (Whitin and Youngs) Let $A > 0$ and $B > 0$. Then for the case of infinite span, $\sigma = \infty$, L has a global minimum which first[1/] occurs at

$$(3.1) \qquad n = \min_{s} \{C_s \geqq B/(A + B)\} .$$

<u>PROOF.</u> The loss function L is in this case convex in s according to the Corollary to Lemma 2. This means that we may search for its minimum by the procedure discussed in the paragraph below (1.11). In detail, we first show that $\Delta L(s, \infty) \geqq 0$ for at least one s. This is immediate from (2.6) whereby, since $C_{s+\sigma} = 1$ in the limit for $\sigma = \infty$,

$$\Delta L(s, \infty) = (A + B) C_s - B$$

and we see that $\Delta L(s, \infty)$ has the same algebraic sign as does

$$(3.2) \qquad C_s - B/(A + B) .$$

Then $\Delta L(s, \infty) \geqq 0$ for at least one s since otherwise from (3.2) we would contradict either $C_\infty = 1$ or $B/(A + B) < 1$. Proof is thus complete and we denote the smallest such s by n as shown in (3.1).

In the context of our allowance list example there are two cases to be distinguished in practice as illustrated in Figure 2. On the left, the minimum occurs at $n = 0$ which would mean that the repair part

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[1/] Since we permit arbitrary probability distributions $\{P_i\}$ it may happen that the minimum may occur for several successive values of s rather than for at most two as in [4] where one of the restrictions was $P_i > 0$ for all i.

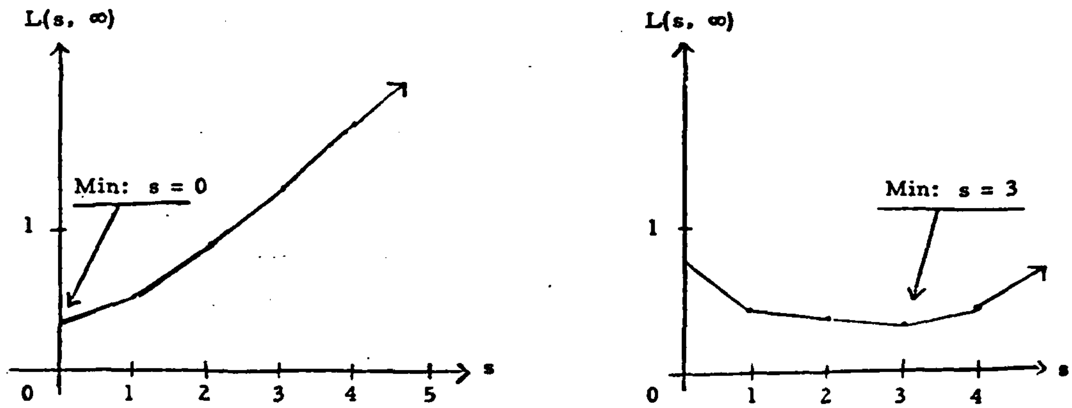

Figure 2. Two examples of minima for $L(s, \infty)$.

should not be carried on board the submarine. In case $n > 0$ as on the right, the item should be carried on board and in quantity n units.

The following corollary is of considerable importance in practice since it exhibits the ratio B/A as the critical determinant independent otherwise of scaling for the penalties A and B as defined in (1.1).

> COROLLARY 1. (Whitin and Youngs) If $A > 0$, $B > 0$ and $\sigma = \infty$, the minimum of $L(s, \infty)$ is determined by the value of the ratio B/A.

> PROOF. If $B/A = \alpha$ then the quantity of $B/(A + B)$ in (3.1) equals $\alpha/(1 + \alpha)$. It is similarly convenient to note that if $B/(A + B) = \beta$ then $B/A = \beta/(1 - \beta)$.

Careful examination of the proof for Lemma 3 taken together with our earlier lemmas reveals that A and B may represent "penalties" of any kind whatsoever, even negative penalties which we equate to "premiums". The problem of minimizing expected total loss, i.e., $L(s, \infty)$, is then in certain cases trivial. However, as we show below following (3.3), we cannot apply (3.1) in all cases for A and B.

> COROLLARY 2. If A and B in (1.1) are arbitrary real numbers there is at most one optimum value n for which $L(s, \infty)$ is minimum as shown in the following table.

Minimum at $s = n$		Shortage Penalty		
		$B < 0$	$B = 0$	$B > 0$
Surplus Penalty	$A < 0$	∞	∞	∞
	$A =$ `	0	0	∞
	$A > 0$	0	0	Unique finite n

PROOF. We use "optimum" to denote the smallest integer at which a global minimum is assumed. Consider $A < 0$. Then if $B < 0$ we have a concave loss function which is the negative of L in Lemma 3. There could be a l)cal minimum at $n = 0$ in a case corresponding to reflection of the right-hand sketch in Figure 2, but there can be no global minimum except $n = \infty$. If $B = 0$, $L(s, \infty) = a(s) A$ is in this case by Lemma 1 decreasing for s sufficiently large and the same holds true if $B > 0$. Thus, in each case for the first row of the table, $n = \infty$ consistent with the condition of premiums for surplus. In the second row, $L(s, \infty) = b(s) B$ and with Lemma 1 we see that L is nondecreasing, zero, or nonincreasing when $B < 0$, $B = 0$, or $B > 0$ so that $n = 0, 0,$ or ∞, respectively. Next, $n = 0$ in case $A > 0$ and $B = 0$ wherein $L(s, \infty) = a(s) A$ is nondecreasing. The only remaining case in the table is $A > 0$, $B < 0$. But always when $\sigma = \infty$,

$$\Delta L(s, \infty) = A\, C_s - B(1 - C_s) \tag{3.3}$$

by virtue of (2.6) so that $\Delta \geqq 0$ for all s when $A > 0$ and $B < 0$, whereupon $n = 0$. This completes the proof.

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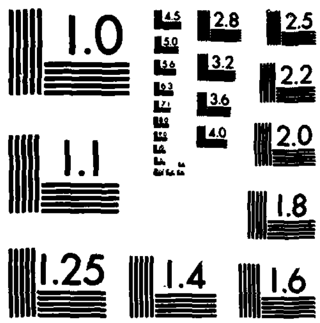

MICROCOPY RESOLUTION TEST CHART
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It is worthy of note that (3.1) cannot be applied in all cases to produce results agreeing with the table. For example, if $B = 0$ and $A < 0$ then in (3.1) we would seek $\min_s \{C_s \geqq 0\}$ and would find $n = 0$ in disagreement with $n = \infty$ in the table. Rather than characterizing the exact applicability of (3.1) for general A and B it seems preferable to suppose that the table given above will be consulted and (3.1) is to be applied only for the case $A > 0$, $B > 0$.

The fundamental result toward which we have been working will now be stated and proved as a constructive procedure for determining the existence and location of integers n for which $L(s, \sigma)$ is minimum.

<u>THEOREM</u>. Let $A > 0$ and $B > 0$. Then $L(s, \sigma)$ has a global minimum which first occurs at say $s = n$. A necessary condition on n is

$$C_n \geqq \{ B/(A + B) \} C_{n+\sigma}. \tag{3.4}$$

If n' satisfies (3.1) then a necessary and sufficient condition is that the present n minimizes $L(s, \sigma)$ over $s = 0, 1, \ldots, n'$.

<u>PROOF</u>. In order that n minimize $L(s, \sigma)$ we must of course have $L(n, \sigma) \leqq L(n + 1, \sigma)$. With the aid of (2.6), this last inequality establishes condition (3.4). By Lemma 2, for any s, $L(s, \sigma)$ is non-negative, concave and nondecreasing in σ. We need more than this to establish the final sentence in the theorem. In fact, writing Δ_s to denote differencing on s, we need to show that although it need not be convex in σ, $\Delta_s L(s, \sigma)$ is itself nonincreasing in σ. This results from (2.6) whereby

$$\Delta_s L(s, \sigma + 1) - \Delta_s L(s, \sigma) = -B\, P_{s+\sigma+1} \tag{3.5}$$

a non-positive quantity, so that for each s,

$$\Delta_s L(s, \infty) \leqq \ldots \leqq \Delta_s L(s, \sigma + 1) \leqq \Delta_s L(s, \sigma) \leqq \ldots \tag{3.6}$$

Let us consider n' satisfying (3.1) which means that for $\sigma = \infty$ the minimum of $L(s, \infty)$ first occurs for $s = n'$: n' is the initial value of s for which $0 \leqq \Delta_s L(s, \infty)$. But then by virtue of (3.6), $0 \leqq \Delta_s L(n', \sigma)$ for every σ. Since $L(s, \infty)$ is convex, $\Delta_s L(s, \infty)$ is nondecreasing in s so that $\Delta_s L(s, \infty) \geqq 0$ for $s \geqq n'$. Hence, we also have $\Delta_s L(s, \sigma) \geqq 0$ for $s \geqq n'$ for any finite σ. We conclude that $L(s, \sigma)$ is nondecreasing for $s \geqq n'$ and n' must be the largest value of s at which a minimum of $L(s, \sigma)$ can occur for any σ. This completes the proof. Notice that we have reduced the problem of minimizing $L(s, \sigma)$ over all the integers $s = 0, 1, 2, \ldots$ to the trivial problem of minimization over a finite set $s = 0, 1, 2, \ldots, n'$.

Several observations are in order at this point. First, (3.1) is clearly the limiting case of (3.4) since in the latter $C_{n+\sigma}$ tends to unity as σ becomes infinite. Second, (3.4) is not a sufficient condition unless $L(s, \sigma)$ is convex in s; from Lemma 2 we see that for general $\{P_i\}$ we cannot guarantee convexity in s. Perhaps the simplest example of possible difficulty from non-convexity would be $\Delta_s L(s, \sigma) = 0$ yet $L(s + 1, \sigma) > L(s + 2, \sigma)$ so that $L(s, \sigma) = L(s + 1, \sigma)$ is not a minimum. We overcome such difficulties, and others, by exhaustive search over the finite range $0, 1, \ldots, n'$. We will now show that exhaustive search over the finite set for s cannot be avoided in the general case for finite span. In order to demonstrate this we first exhibit a case where $\min_s L(s, \sigma)$ occurs neither at the first nor at the last s for which

$\Delta_s L(s, \sigma) \geqq 0$ .. Such a case is given in Figure 3 where $L(s, 1)$ possesses both local minima and local maxima. Notice that $\min_s L(s, 1)$ occurs at $s = 4$ while $\min_s L(s, \infty)$ is achieved for $s = 16$. A sketch for $L(s, 1)$ and $L(s, \infty)$ is contained in Figure 4. We complete the demonstration that our theorem cannot be improved unless restrictions are placed on A, B, $\{P_i\}$, by exhibiting an example in Figure 5 where local minima of $L(s, 1)$ are locally concave. Here, $L(s, \infty)$ is minimum for $s = 5$ while $L(s, 1)$ is minimum at $s = 4$. Local minima at $s = 0, 2$ and 4 form a concave set in Figure 5 whereas local minima in Figure 4 form a convex set. The conclusion is that for practical purposes our theorem and its exhaustive search cannot be improved. Finally, it may be instructive to note that (3.4) is equivalent to

$$C_n \geqq \{B/A\} \ \{P_{n+1} + P_{n+2} + \ldots + P_{n+\sigma}\} \tag{3.7}$$

whose right-hand member again fixes attention on the critical ratio (B/A), this time taken together with probability of demand over the range $n+1, n+2, \ldots, n+\sigma$.

It is clear that we may state an exact analogue to Corollary 1, Lemma 3.

> COROLLARY 1. If $A > 0$ and $B > 0$, the minimum of $L(s, \sigma)$ is determined by the value of the ratio B/A.

PROOF. The proof for Corollary 1 to Lemma 3 applies.

s	P_s	a(s)	b(s)	L(s, 1)	L(s, ∞)
0	0.1	0	9.0	45	450
1	0	0.1	8.1	46	406
2	0.1	0.2	7.2	42	362
3	0	0.4	6.4	44	324
4	0.1	0.6	5.6	41	286
5	0	0.9	4.9	44	254
6	0.1	1.2	4.2	42	222
7	0	1.6	3.6	46	196
8	0.1	2.0	3.0	45	170
9	0	2.5	2.5	50	150
10	0.1	3.0	2.0	50	130
11	0	3.6	1.6	56	116
12	0.1	4.2	1.2	57	102
13	0	4.9	0.9	64	94
14	0.1	5.6	0.6	66	86
15	0	6.4	0.4	74	84
16	0.1	7.2	0.2	77	82
17	0	8.1	0.1	86	86
18	0.1	9.0	0	90	90
19	0	10.0	0	100	100
20	0	11.0	0	110	110

Figure 3. A numerical example: A = 10, B = 50.

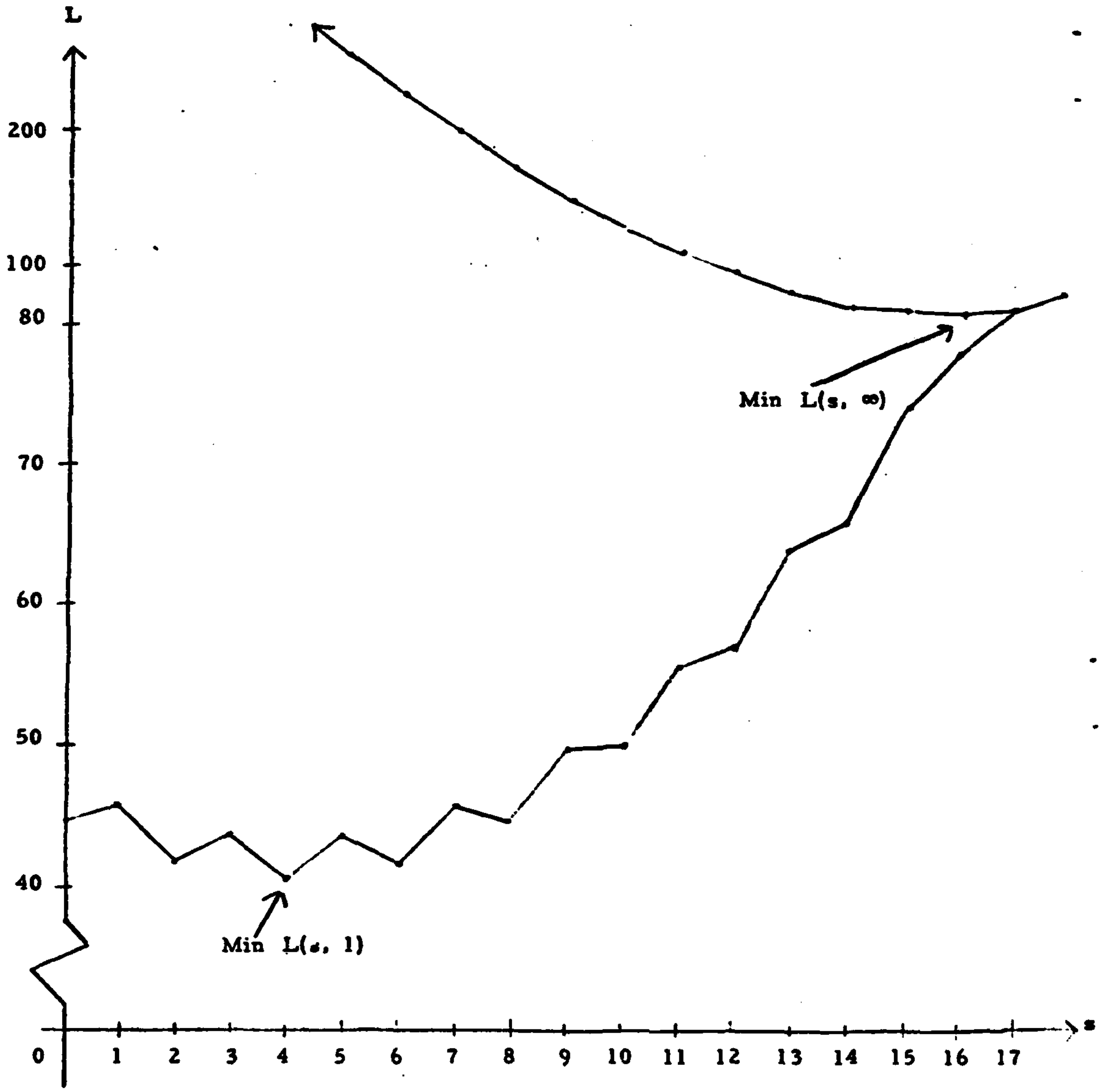
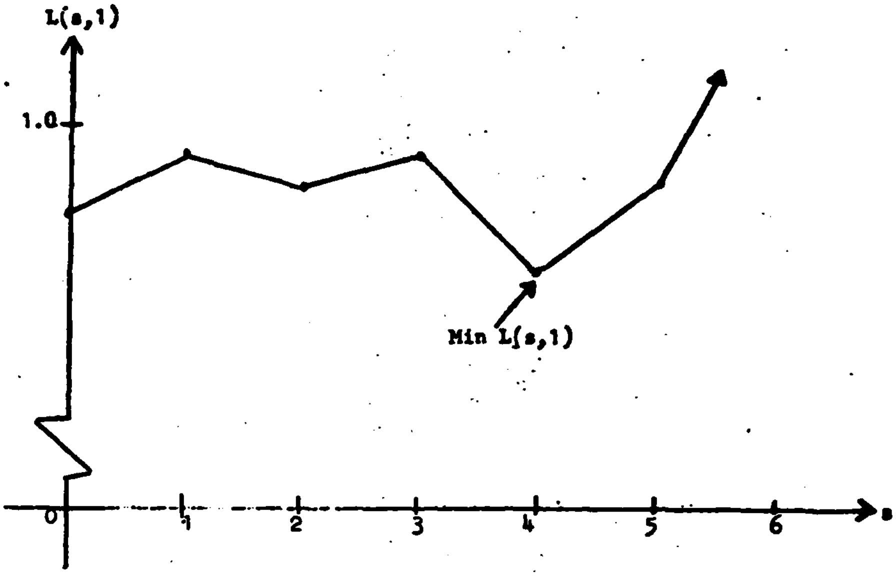


Figure 4. A sketch of two loss functions.



s	P_s	a(s)	b(s)	L(s,1)	L(s,∞)
0	0.03	0	4.58	0.97	4.58
1	0.01	0.03	3.61	0.99	3.64
2	0.05	0.07	2.65	0.98	2.72
3	0.08	0.16	1.74	0.99	1.90
4	0.20	0.33	0.91	0.96	1.24
5	0.35	0.70	0.28	0.98	0.98
6	0.28	1.42	0	1.42	1.42
7	0	2.42	0	2.42	2.42
8	0	3.42	0	3.42	3.42

Figure 5. An example with A = B = 1.

<u>COROLLARY 2.</u> If A and B in (1.1) are arbitrary real numbers there is at most one optimum value n for which $L(s, \sigma)$ is minimum. The table in Corollary 2 of Lemma 3 applies to the present case for n.

Minimum at $s = n$		Shortage Penalty		
		$B < 0$	$B = 0$	$B > 0$
Surplus Penalty	$A < 0$	∞	∞	∞
	$A = 0$	0	0	∞
	$A > 0$	0	0	Unique finite n

<u>PROOF.</u> If $A < 0$ then for s sufficiently large, $\Delta_s L(s, \sigma) < 0$ and $n = \infty$. If $A = 0$, $L(s, \sigma) = \{b(s) - b(s + \sigma)\} B$ where the quantity within $\{\ \}$ is nonincreasing in s as may be verified with (1.13). This means that just as in the earlier Corollary 2 for $\sigma = \infty$, the present L is nondecreasing, zero, or nonincreasing according as $B < 0$, $B = 0$, or $B > 0$, respectively. Continuing to row 3, if $B = 0$ then L is independent of σ and $n = 0$. Finally, as was done above, if $A > 0$ and $B < 0$ we verify $n = 0$ with (2.5) by proving $\Delta L(s, \sigma) \leq 0$ for all s. This completes the proof.

4. <u>Inventory models.</u>

The theorem of the preceding section and its corollaries may

be used to handle a variety of situations represented by the process of minimizing $L(s, \sigma)$ as a function of s for given $\{P_i\}$ A, B and σ. With Corollary 2 we can immediately determine whether or not a unique finite minimum is achieved. Either $n = \infty$ or else there is an integer n at which $L(s, \sigma)$ first achieves its minimum. Then either $n = 0$ from the table or else n is determined by the finite process of the theorem.

In the present paper we limit ourselves to a simple illustration for application to inventory models. We return to our example of a submarine allowance list problem and we suppose that $\{P_i\}$, A, B and σ have been specified for each allowance list candidate. Of these four we will consider that $\{P_i\}$ and σ are fixed for each candidate: $\{P_i\}$ will have to be accepted as given and σ similarly is a general constraint which we will not be able to change. We require next that a "unit cube" which is a unit stowage volume in cubic feet, c, be specified for each candidate. Then our problem will be to determine an allowance list which utilizes a total volume of C cubic feet. Our procedure could be the following.

a. We arrange the allowance list candidates in a "priority" sequence of nonincreasing essentiality, e.g., by techniques in [1].

b. Using a given set of A's and B's (or equivalently the ratios B/A) we proceed in "priority" order to minimize expected loss $L(s, \sigma)$ for each individual allowance list candidate.

c. An entire allowance list is determined through specification of exact procedures for starting, continuing and finally terminating the steps b.

While we wish to avoid detailed consideration of possibilities for step c, the following remarks should serve to illustrate general techniques. First, we could proceed through the entire list of candidates and then compare C' our total accumulated stowage space requirement upon completion with our limit C. We would then ordinarily compute measures of expected performance (e.g., the per cent of candidates for which $n = 0$) and take these together with C' vs C in order systematically to revise individual A's and B's preliminary to another pass. Of course any pass could be terminated at a point in the priority list prior to the actual end point. In such manner our entire allowance list would be determined by an iterative process approximating a total stowage space requirement for C cubic feet through individual minimizations of loss functions for individual repair part candidates. We have had experience with such processes and we plan to present them in subsequent papers of the present series.

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POLARIS LOGISTICS STUDIES
Number 2

POLARIS ALLOWANCE LIST INPUT DATA

MARVIN DENICOFF
JOSEPH FENNELL
W. H. MARLOW
HENRY SOLOMON

Serial T-154
18 January 1963

THE GEORGE WASHINGTON UNIVERSITY
LOGISTICS RESEARCH PROJECT

Contract Nonr761
Task 03, Project NR 345 107
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THE GEORGE WASHINGTON UNIVERSITY
Logistics Research Project

Abstract
of
Serial T-154

POLARIS ALLOWANCE LIST INPUT DATA

MARVIN DENICOFF
JOSEPH FENNELL
W. H. MARLOW
HENRY SOLOMON

The object of this paper is to provide a careful description of data which are presently available for Fleet Ballistic Missile submarine allowance list determinations. Such a description has turned out to be necessary for several reasons. First, it is required in order to achieve sufficient precision to permit adequate problem formulation. Second, the needs for data processing have been substantial: one has to be able to write instructions which will lead to submittal of correct data, one has to be able to communicate with computers, etc. Finally, the present paper has been written for use in evaluating various proposed allowance list methodologies where one has to be able to specify precisely the range for the measurements comprising the evaluation. Precise definitions of data entries are given and layouts are prescribed for automatic data processing records so that it is possible to define an allowance list candidate. This is a part application which leads to acceptable arithmetical input for an allowance

list optimization model. Various properties are developed for allowance list candidates and standard terminology is adopted accompanied by appropriate notation. There is also included a precise description of the format for a published "Optimum COSAL" allowance list. The paper concludes with summaries of certain data for the case of USS GEORGE WASHINGTON (SSB(N) 598). The present paper is judged to be of significance for Navy line-item inventory problems generally rather than for Polaris alone since the basic input data for military inventory problems are much the same anyway. One distinguishing feature of the subject data is that they are now in successful operational use.

PREFACE

The present study is the second of several papers to be issued by this Project as Polaris Logistics Studies. Subsequent papers will consider allowance list determinations, FBM load lists for deployed tenders, ashore supply point problems, provisioning and procurement policies, and finally the general problem of providing logistics information and control systems to permit overall satisfactory logistics.

It will become apparent that the present series will represent a somewhat diverse range of interests. In addition to the fact that a somewhat heterogenous set of research techniques will appear there is one feature which deserves special comment. This refers to the fact that careful attention is given to the underlying situations to which the methodology is to apply. It turns out that this introduces the need for considerable precision of terminology in engineering and logistics areas which unfortunately include areas notorious for their lack of standards, e.g., the problem of definition of a "component" as opposed to an "equipment". Nevertheless, a substantial part of the contribution of the present series is judged to consist of its relevance for practical problems; this has required that unswerving attention be paid to the exigencies of the background situations and their definitions.

It is a pleasure to acknowledge the support of the Logistics and Mathematical Statistics Branch of the Office of Naval Research under whose contracts this work has been performed. In just the same way, appreciation is due the Technical Director, Special Projects Office, and his Assistant for Material Support who are co-sponsors of this research

by means of transfer of necessary funds to the Office of Naval Research. Mention should also be made of the fact that the Bureau of Supplies and Accounts and its field activities have been collaborators in the present studies. Finally, it is most appropriate to cite the essential assistance and support provided by the Logistics Research Project administrative and clerical staff and by the members of the Project Computation Laboratory who were essential for this work.

W. H. Marlow

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0. Introduction and summary.

The object of this paper is to provide a careful description of data which are presently available for Fleet Ballistic Missile (FBM) submarine allowance list determinations. As it is herein defined, the allowance list for a vessel is the specification of the range and depth for wearable installed parts to be carried on board the ship for use by the ships force in direct support of installed components. A considerable portion of the present paper actually consists of definitions which are required in order to be able to express exactly what we mean by the technical terminology employed in the preceding sentence: range, depth, wearable installed parts, use by ships force, direct support, and installed components. Certainly the general

[1]The preparation of this paper was sponsored by the Office of Naval Research and the Special Projects Office. Reproduction in whole or in part is permitted for any purpose of the United States Government.

[2]Navy Bureau of Supplies and Accounts

meaning of each of these is clear, at least in broad terms, to anyone who has had any contact with shipboard inventory problems. Nevertheless, the provision of suitable definitions turns out to be an onerous and non-trivial task.

There is considerable difficulty of communication on account of conflicting terminology in various quarters; e.g., the problems of distinguishing between "parts", "components", "equipments", "assemblies", "modules", etc., etc. are well known for their difficulty. These difficulties naturally increase when these terms must themselves be modified as in the above case of "installed part". Our intent in the present paper will be to formulate definitions which are adequate and convenient for allowance list purposes without any attempt at providing a universally acceptable language for engineering documentation. A second point of difficulty in providing suitable definitions is that many of the concepts are somewhat elusive to the point of causing adequately precise descriptions to be rather cumbersome of expression. A simple and perhaps not overly elusive example of this would be the distinction between a "part" and a "part application". The former refers to a specific engineering entity such as a 1/2 watt carbon 220 ohm 10% resistor. On the other hand, a "part application" denotes an ordered pair, i.e., a part tied to a specific next higher parent assembly. For example, a given resistor may appear in several different parent assemblies. There are approximately 31,000 parts and 56,000 part applications making up the set of allowance list "candidates" for an FBM submarine, so that in any discussion of "range" we must be careful to specify exactly which group we mean. There is a more fundamental difficulty in this particular example; this concerns the manner in which the admissible "candidates" are defined. For example, should only parts which are stocked in the supply system be admitted or should the maximal range be permitted to include <u>any</u> part from the bill of materials? In the Optimum COSAL Program our goal has been the latter approach. While there

are difficulties associated with obtaining the requisite data, these do not turn out to be insurmountable. Certain of the difficulties are associated with what may be noted as a third general type of problem connected with the provision of adequate definitions: the existence of discrepancies between various procedures of different organizations. Just as in the case of our first general topic above concerning differing terminologies, procedural differences often are completely valid consequences of different organizational missions, responsibilities, or in brief, the nature of the problems being attacked. In the present report, we intend to place major stress on the conceptual development. In cases where there exist important procedural differences between organizations, we shall set as our first goal an adequate problem formulation and we will then relate the different existing procedures to the basic problem. Principal examples here include the different "component" population structures utilized by the Special Projects Office and the various Bureaus and also the different techniques (Allowance Parts Lists) employed by different Inventory Control Points for the representation of "parts" populations. In summary, we shall endeavor to hold a middle ground between completely idealistic definitions on the one hand and exhaustive journalistic representations of Navy terminology and usage on the other.

Sections 1 and 2 contain mainly definitions of terms accompanied by a thread of commentary having to do with general significance, a few elementary relationships and certain features which are important for automatic data processing. With these definitions in hand, it is easy to describe the format of a published allowance list. This is done in Section 3 for the case of the Optimum Coordinated Shipboard Allowance Lists or "Optimum COSAL's" which are the allowance lists of concern for the present series of papers.

Section 4 is devoted to a definition of an allowance list candidate: a part application which leads to admissible input for an allowance list

optimization model. In order that a part be a candidate for an FBM submarine allowance list, it is necessary that it satisfy quite a few conditions: e.g., candidates must be parts which the ships force is capable of installing while on patrol and hence, for example, they may not include parts which are only accessible during dry-docking. Similarly, they do not include parts for which maintenance policy forbids replacement by ships force. As another example of a necessary criterion for an allowance list candidate as we define one, we require that the part have a quantitative population: if the "number installed" for the part is really not a number but instead is designated as "AR" for "as required" we conclude that it should not be considered to be installed at all and we eliminate it. In this way it will be removed from the parts for which in-line calculation will subsequently be made. After accomplishing the definition of allowance list candidates in Section 4, the remainder of the section is devoted to further development of their properties. Additional data are derived for use as input for subsequent allowance list determinations: some of these data are simply numerical such as "population", some are statistical in nature relating to probabilities of future demands for the parts, and others amount to scaling of data for use as numerical input to later calculations.

Section 5 is devoted to summaries of distributions of various input data for the USS GEORGE WASHINGTON (SSB(N) 598) allowance list candidates. These serve to sharpen appreciation for the nature of the allowance list problem. Indeed, Section 5 amounts to a summary numerical description of the vessel for allowance list purposes.

Despite the fact that the present paper is limited to Polaris allowance lists, the reader may be assured that more widespread application is perfectly possible. In fact, a great many of the data are available for other vessels. It has turned out that FBM submarines have been used as the occasion to introduce more advanced inventory control systems than heretofore have ever been employed on a large scale by the Navy. This has resulted in the first place

from the availability of new types of data such as military essentiality data [3] which were developed initially for conventional submarines [2] and then were refined to apply specifically to the Polaris weapons system. In the second place, the more advanced techniques were made possible by the existence of data which, while not new in nature, were nevertheless not previously generally available for use. Examples here would be "population" data, packaged stowage space required, i.e., "unit cube", usage estimates, and others. Finally, the Polaris weapons system led directly to the development (and implementation) of new allowance list methodology for determining actual lists under the 'Optimum COSAL Program". This came about as a result of the decision to carry out the research using actual data and to perfect the techniques meanwhile producing the best practicable allowance lists. The resulting theoretical models will be described in subsequent papers in the present series at which time it will become apparent as to the nature of their relevance for logistics problems in addition to the original Polaris problems. In much the same way the contribution of the present paper is judged to be wider than to Polaris allowance lists alone: for one thing, it will be seen to assist problem formulations at higher echelons than the submarine itself such as that of the deployed FBM submarine tenders. In addition, the present paper is believed to be of significance for Navy line-item inventory problems generally -- the basic input data for military inventory problems are much the same anyway. One distinguishing feature of the subject data is that they are now in successful operational use.

In conclusion, the present paper has turned out to be necessary for several reasons. First, it is required in order to achieve sufficient precision to permit adequate problem formulation. Second, the needs for data processing have been substantial: one has to be able to write instructions which will lead to submittal of correct data, one has to be able to communicate with computers, etc. Finally, the present paper has been written for

use in evaluating various proposed allowance list methodologies where one has to be able to specify precisely the range for the measurements comprising the evaluation.

1. Component-equipment data.

This section defines what are often termed Index Data by virtue of the fact that they are the data used to generate the Index of a vessels allowance list. The Index is made up of listings designating the component-equipment configurations installed on the subject vessel. Use of the hyphenated expression "component-equipment" in the preceding sentence and in the heading of the present section corresponds to the fact that we have to deal with entities which typically are designated by either or both of these appellations. That is, while they may even be given different labels, we recognize three principal cases: component-equipment pairs, components, and equipments. Whatever they may be called, the idea is that they constitute "parent next-higher assemblies" for installed parts. (One approach to what they may as well be called is defined below in 12) Component-Equipment MEC code.)

The designation actually used by the Navy for the records under discussion is Component Data Master Records. The exact layout of the subject data record is displayed in Figure 1. Taken together with the definitions and explanations included below for the individual record fields, Figure 1 specifies the complete range of data required at the component-equipment level in the Optimum COSAL Program. This will become clear as the individual record fields are discussed below in order.

1) Hull type is the alphabetic hull designation which is "SSBN" for FBM submarines.

2) Hull number makes up a numeric field containing the actual hull or bow number to which the record applies. The union of Fields 1 and 2 is denoted by VESSEL NUMBER.

COMPONENT DATA MASTER RECORD LAYOUT				
Field No.	Notation for Field	Contents	Length of Field	Record Positions
1.		Hull type	5	1- 5
2.		Hull number	4	6- 9
3.	CID	Application code	11	10- 20
4.		Program Support code	2	21- 22
5.	SA	Service Application code	6	23- 28
6.		Equipment and/or Component nomenclature	48	29- 76
7.		Service Application nomenclature	55	77-131
8.	MEC	MEC class code 1/	4	132-135
9.	QC	Quantity of Component installed	4	136-139
10.		ECN-APL column number	1	140
11.		Notes	2	141-142
12.	MEC-CE	Component-Equipment MEC code	6	143-148
13.		Sub-system code	2	149-150
14.		Blank	3	151-153
15.		Security classification	1	154
16.		End of record	1	155

Figure 1

1/ See the text for a discussion of this field. Eventually, this field will contain the ordinal locator for the CID based on p = 1: 0116, 0115, . . . , 0088 where "116" denotes highest worth. At present this field contains 0001, 0002, . . . , 0029 where "1" denotes highest worth.

3) Application code, CID, is contained in an alpha-numeric field, left justified with blanks following. The notation for the field is "CID" but, as will now be explained, this is a field with somewhat varying content sometimes containing codes which, strictly speaking, are not what the Navy terms Component Identification codes. The purpose of this field for the case of allowance lists is to identify the engineering entity which is a possible "parent next-higher assembly" for installed parts. (That is, there may or may not actually be parts installed since it is possible to have "No repair parts applicable".) The actual content of this field is the Allowance Parts List or APL code which identifies the technical document providing detailed information on this particular entity. (See Figure 8 below.)

DEFINITION. An admissible CID is a component-equipment to which there is assigned a CID code which satisfies exactly one of the following conditions.

a) Position 11 in the Component Data Master Record does not contain "+".

b) Positions 10, 11 contain "P", "+", respectively.

Category b) defines "preliminary CID's" which for our present purposes need not be distinguished from those satisfying a). The CID's which are excluded by the above, i.e., those with inadmissible CID codes, turn out to correspond generally to lists of items of equipage, or certain material requirements for particular systems. These lists, called Equipage Category Number-APL's, ECN-APL's, may consist of "repair parts" such as for periscopes wherein a single list may apply to several ships by means of its having several different columnar entries. On the other hand, the ECN-APL's may consist of lists of tools, instruments, messing equipment, or may even be prepared solely for information purposes to supply reference material required to be able to manufacture certain gear. On the basis of the facts, it is proper to state the following.

DEFINITION. An entity is defined to be an admissible parent CID if and only if it is an admissible CID to which there corresponds at least one part which is an allowance list candidate as defined below in Section 4.

For purposes of allowance list determinations as understood in the present paper, there are no problems associated with the inadmissible CID's. This is a result of the fact that the associated allowance list quantities, if any, are established by decree. In other words, the range of inputs to a mathematical allowance list model may be restricted to data arising from admissible parent CID's only. It would be expected, and it is indeed accomplished, that "all" CID's are covered in an allowance list determination. But our interest in the present paper will be directed mainly toward those items for which there exist problems of how to determine the allowance list quantities for wearable installed parts, namely the admissible parent CID's.

4) Program Support code is contained in an alpha-numeric field, left justified, identifying the Inventory Control Point which has program support, i.e., weapons management, responsibility for the given CID. For example, "H", "Z", "N" denote SPCC, OSO, ESO, respectively.

5) Service Application code, SA, is an alpha-numeric code denoting the service or end use of the equipment. There exist two varieties at present.

a) Service Application code (SA): a five position alpha-numeric code in Positions 23-27 with an asterisk (*) in Position 28.
b) Component Usage Designator (CUD): a six position alpha-numeric code.

The CUD's were assigned at one time by the Special Projects Office in order to identify each of their components and equipments with its actual location or "address"; CUD's are no longer being assigned so that eventually this field will be limited to codes a). As indicated in Figure 1, we will use 'SA' to

denote the contents of this field whether they be CUD's or "true" SA's.

DEFINITION. An admissible parent SA is defined to be an SA to which there is assigned at least one admissible parent CID.

In general, several CID's may be assigned the same SA code which indicates that together they accomplish the specified service or end use denoted by the SA code. On the other hand, a given CID may of course be assigned to different SA's. There is a separate Component Data Master Record prepared for each distinct CID, SA pair.

For example, CID 882100002 identifies a particular valve. This one valve has two services. A total quantity of eight of this valve is installed: one is assigned to SA code OACMF*, "Air conditioning-piping", and seven appear with OAHMB* which denotes "Refrigeration-piping".

6) Equipment and/or component nomenclature is normally the Federal name of the item, possibly followed by modifiers. The noun name is usually not abbreviated, a " + " generally separates the noun name from its modifiers, but the actual contents of the field may be expected to vary in practice.

7) Service Application nomenclature is a brief description of the service or end-use of the component such as "oxygen system-piping", or "periscope-star tracker".

8) MEC class code, MEC, corresponds to the ordinal locator or MEC code [3] for the component-equipment. Originally, this field was numeric containing one of 0001, 0002, ..., 0029 where " 1 " denoted the highest military essentiality and " 29 " the lowest. Eventually, it is hoped that this field will contain numbers 0116, 0115, ..., 0088 consistent with [3] where " 116 " denotes highest worth. See the related material contained in Field No. 12 described below in 12).

9) Quantity of Component installed, QC, is a numeric field representing the actual number installed on-board for this particular CID for the given SA. For the case of ECN-APL's, the present field is blank. (See Field 10) below.)

10) ECN-APL column number denotes the applicable column number 1, 2, . . . , 8 for the given vessel. Note that this does not apply to admissible CID's but only to those inadmissible (to the model), for which allowance quantities are found by table look-up in which case this field specifies the appropriate column.

11) Notes consists of an apha-numeric field containing special indicators assigned by Inventory Control Points and defined in the Table of Notes in the Appendix to the allowance list. For the purposes of the present paper, these notes have no significance: the currently applicable notes apply mainly to inadmissible CID's with the exception that there is a symbol "%" used in order to call attention to certain choices which are possible between interchangeable items, usually consequent to some design change.

12) Component-Equipment MEC code, MEC-CE, represents the raw MEC sextuplet code of [3]. On the basis of this field, it is conveniently possible to classify the "nature" of the CID as follows.

a) In case there are no blanks, the CID represents a Special Projects component-equipment pair with MEC-CE code uvw xyz where each of u, v, w, x, y, z is one of 0, 1 or 2.

b) In case Positions 146-148 contain blanks while 143-145 do not, then the CID represents simply a component which is not assigned to a parent equipment. Here the MEC-CE code is uvw bl bl bl. (This is the normal case for Bureau of Ships material comprising the ship sub-system.) Again, each of u, v and w is one of 0, 1 or 2.

c) In case Positions 143-145 contain blanks while 146-148 do not, then the CID represents simply an equipment to which no components are assigned. Here the MEC-CE code is bl bl bl x y z. (This is a relatively rare case found for certain Special Projects equipments.) Here x, y, z assume values 0, 1 or 2.

d) In case the entire field, 143-148, contains blanks there is the discrepancy of missing data.

13) Sub-system code is contained in an alpha-numeric field, left justified, identifying the parent sub-system for the given CID-SA pair as follows.

Sub-system	Code
Launcher	L
Fire Control	F and FX[1/]
Navigation	N
Missile	M
Missile Test and Readiness	R and D[2/]
Ship	SS

14) Blank is an unassigned field.

15) Security classification field is used for the subject purpose utilizing "C" for Confidential and blank otherwise.

16) End of record is contained in Position 155.

[1/] The code "FX" actually denotes training devices associated with the Fire control sub-system.

[2/] The code "D" will eventually disappear since it denotes certain equipment which has been superseded.

In conclusion, the present section has described the Component Data Master Records which exist in a separate file for each FBM submarine bow number, one record per distinct CID, SA pair.

2. Parts data.

This section defines what are sometimes termed Optimum COSAL SNSL, or "Stock Number Sequence List", data by virtue of the fact that they are the data used to generate the SNSL of a vessels Optimum COSAL. The SNSL consists of a listing wherein there is one entry per part to print the stock number, nomenclature and certain other data including a list of all Application codes or CID's in which the part appears. It will be seen that the data described below include many data fields not printed in the SNSL: in fact there are certain data entries defined which are not even required for allowance list determinations. What this means is that the "parts data" of the present section actually form a complete set of basic parts input data sufficient for general logistics calculations rather than those sufficient for allowance lists alone. Consistent with these considerations is the file designation actually used by the Navy for these records, namely the Optimum COSAL Repair Part Data Master Records.[1/] (This too

[1/] These records are to be distinguished from the Regular COSAL Repair Part Data Master Records which are 175-position records which do not vary by Vessel Number. These latter records do not contain "Hull type" and "Hull number" as shown in Figure 2 below; instead, there is one record per Component, Stock Number combination. Positions 1-162 of the Regular COSAL record are identical with Positions 11-172, respectively, of the Optimum COSAL record as shown below in Figure 2. Positions 163-171, 172, 173, 174 contain respectively "blanks", "Number of Requests", "Internal Rejection Indicator", and "Internal Action Indicator". Position 175 contains "End of Record". No further reference will be made in the present paper to these records so that "parts data" or "parts record" will hereafter be understood to refer to the Optimum COSAL record of Figure 2.

is somewhat misleading since these records include parts which are not "repair parts" at the shipboard level [see Item Code, Field 15, below] but this should cause no difficulty.)

The exact layout of the parts records is displayed in Figure 2. Taken together with the definitions and explanations included below for the individual record fields, Figure 2 specifies the complete range of parts input data. In the Optimum COSAL Program there is one distinct "parts record" per distinct part application per vessel.

1) Hull type is the same as in Component Data Field 1.

2) Hull number is the same as in Component Data Field 2. Again, the union of Fields 1 and 2 is denoted by VESSEL NUMBER.

3) Blank is self-explanatory.

4) Application code, CID, is the same as in Component Data Field 3, i.e., this field identifies the parent CID for the part to which the record applies.

5) Program Support code is the same as in Component Data Field 4.

6) Supply Support code is contained in an alpha-numeric field, left justified, identifying the cognizance symbol associated with the Supply Support ICP, e.g., H for SPCC, N for ESO, etc. This code identifies the inventory control responsibility for specific commodities of material and so is associated with the part, i.e., the SN. On the other hand, Program Support, Field 5), is related to weapons system management and therefore relates to the CID.

7) Stock Number, SN, is contained in an alpha-numeric field, left justified, to identify the part. This may be the Federal Stock Number (FSN), Manufacturers Drawing/Plan and Piece Number, Manufacturers Part Number or a Reference Symbol Number. The most common entry is the FSN which is entered in 13 positions as follows.

OPTIMUM COSAL REPAIR PART DATA MASTER RECORD LAYOUT				Page 1 of 2
Field No.	Notation for Field	Contents	Length of Field	Record Positions
1.		Hull type	5	1- 5
2.		Hull number	4	6- 9
3.		Blank	1	10
4.	CID	Application code	11	11- 21
5.		Program Support code	2	22- 23
6.		Supply Support code	2	24- 25
7.	SN	Stock Number	20	26- 45
8.	CUBE-UA	Cube per UA	6	46- 51
9.	WT-UA	Weight per UA	6	52- 57
10.	PRICE-UA	Price per UA	8	58- 65
11.		Price code	1	66
12.		Shelf Life	2	67- 68
13.		Lead Time	2	69- 70
14.	UE-S	Usage Estimate-Ship, in RU	7	71- 77
15.		Item code	1	78
16.	UA	Unit of Allowance	2	79- 80
17.		Environmental code	1	81
18.		Notes	2	82- 83
19.	UI	Unit of Issue	2	84- 85
20.		Part nomenclature	25	86-110
21.	MEC-P	Part MEC code	1	111
22.		Source code	2	112-113
23.		Maintenance code	2	114-115
24.		Recoverability code	1	116

Figure 2

OPTIMUM COSAL REPAIR PART DATA
MASTER RECORD Page 2 of 2
LAYOUT

Field No.	Notation for Field	Contents	Length of Field	Record Positions
25.	QPC	Quantity Installed per Component	4	117-120
26.	RU	Replacement unit	4	121-124
27.		Manufacturers code	5	125-129
28.		Reparable Return Rate	3	130-132
29.		Wearout Rate	3	133-135
30.		Type of Repair Activity	1	136
31.		Service Life	4	137-140
32.	UE-T	Usage Estimate Tender in RU	7	141-147
33.		ECN Table Contents - Column 1	3	148-150
34.		- Column 2	3	151-153
35.		- Column 3	3	154-156
36.		- Column 4	3	157-159
37.		- Column 5	3	160-162
38.		- Column 6	3	163-165
39.		- Column 7	3	166-168
40.		- Column 8	4	169-172
41.	QC	Quantity of Component Installed	4	173-176
42.		MEC Data	4	177-180
43.	AQ-RU	Allowance Quantity in RU[1]	4	181-184
44.	MEC-CE	Component Equipment MEC code	6	185-190
45.	MEC-P	Part MEC code	1	191
46	MEC	Ordinal Locator MEC code	4	192-195
47.	MEC-INV	Inverse MEC code (10 000 - MEC)	5	196-200
48 ff.		Computational Fields[2]	184	201-384
		End of Record	1	385

Figure 2 (Cont'd.)

[1] Positions 325-328 contain AQ-LA, the Allowance Quantity in Units of Allowance. This is the quantity in pieces actually printed in the allowance list. Basic calculations for admissible C D s are made in terms of "sets" for AQ-RU. A part is an allowance list candidate if and only if following an Optimum COSAL calculation Field 43 is not blank. (See the text for equivalent definitions and explanations.)

[2] Computational Fields are displayed below in Figure 14.

Positions	Contents
26-27	FSG: Federal Supply Group code
26-29	FSC: Federal Supply Class code
30	"+" character
31-38	FIIN: Federal Item Identification Number written with a "+" in Position 34.

(In case Field 7 contains an FSN the Item Number, IN, is defined to be the FIIN, otherwise the IN is the contents of the entire field. See Section 4 below.)

8) Cube per UA, CUBE-UA, is measured in cubic feet to 4 D, i.e., as xx.xxxx but the decimal point is not written in the record. This quantity is the volume or cube of the packaged item for one unit of allowance as stowed on-board the vessel. Instructions call for the volume to be computed to 5 D with round-off to 4 D.

9) Weight per UA, WT-UA, is measured in pounds to 2 D, i.e., as xxxx.xx but the decimal point is not written in the record. This weight represents the packaged item for one unit of allowance as stowed on-board the vessel.

10) Price per UA, PRICE-UA, is measured in dollars to 2 D, i.e., as xxxxxx.xx but the decimal point is not written in the record. This price is the actual or best estimated price for one unit of allowance. Estimated prices are designated by an asterisk (*) in Field 11) Price code.

11) Price code contains an asterisk (*) in case unit price is an estimated price and is blank otherwise.

12) Shelf life is recorded in months to indicate that the item has certain physical and material characteristics which limit its storage or shelf life. This quantity represents minimum shelf life in months and items having a shelf life rating of more than 3 years are supposed to have this field blank.

13) Lead time represents average procurement lead time, as defined in [7], expressed in months. In case lead time is less than 3 months this field is supposed to be blank.

14) Usage Estimate-Ship, UE-S, consists of one of two possible types of entry defined as follows.

a) A non-zero estimate to 4 D, i.e., xxx.xxxx but the decimal point is not written in the record. This quantity is an estimate of the average number of replacement units of the part which will be required by ships force annually per part application on account of one unit of the given component.

b) A two character entry 'NU', left justified, with blanks following for "No Usage" which serves to remove the part from consideration for stocking at the ship level on account of the given component.

As is indicated in the above descriptions, this field relates the part identified by the SN in Field 7 to the specific component identified by the CID in Field 4. This means that for a given SN the contents of the present field may vary over different CID's. In view of the fundamental importance of the UE-S field, a detailed treatment will be included here to indicate the manner in which these data are generated.[1/]

The UE-S is based on the average number of units of the part which will be required for replacement per year. This replacement refers solely to work expected or likely to be done by ships force on account of one unit of the given component only. Use of the modifiers "expected or likely to be done" in the preceding sentence corresponds to the interpretation required so that an "average" in a probability sense may result. However, notice that UE-S

[1/] The reader with experience in probability and shipboard logistics may find the definitions implicit in a) and b) to be sufficient. However, it has been found that the UE-S data are generally misunderstood so that the rather lengthy exposition included immediately below may assist even the experienced reader who does not wish to analyze the statements a) and b) with the care generally required to absorb a careful mathematical "definition".

may be greater than unity so that it is itself not a probability. The actual meaning in numerical terms may be illustrated as follows. Assuming there were 10,000 units of this part installed in the given component, if it were then the case that on the average one of these units would be replaced per year, then the appropriate UE-S would be 0.0001. In order to obtain this estimate it is of course not required that there actually be 10,000 units installed. In fact, there may be only one unit installed of the part, i.e., QPC = 1 and nevertheless UE-S = 0.0001. This can be illustrated by any one of the first three examples in Figure 3 where QPC = 1. Continuing to cases where QPC > 1, the common feature of all the examples in Figure 3 is that a deterministic assumption is made, namely

(QPC) x (QC) x (Time) x (UE-S) = Units Required

so that the present approach may itself be labeled deterministic. It will be noticed that the product of the first three terms, QPC x QC x Time, equals 10,000 (part application-years) for each of Examples 1-5 while it changes to 50,000 for Examples 6 and 7 since in these last two the requirements increase five-fold. The point to be made is that the technician who supplied the UE-S = 0.0001 could have thought in terms of any one of the first seven situations depicted in Figure 3 in order to decide

"1 out of 10,000 opportunities"

as his estimate of the "average" number to be used.

Examples 8 and 9 in Figure 3 illustrate UE-S = 0.0500 or "5 out of 100 possibilities". These estimates could of course represent precision to 4 D, i.e., to the nearest ten-thousandth; however, they might instead represent estimates to the nearest 0.01. The fact is that UE-S is recorded with seven positions xxx.xxxx in order to cover all conceivable cases; this does not require that precision extend in every case to 4 D. If the technician could only estimate to tenths then the three low order positions would be non-significant and UE-S might be regarded as say 2.0. This would be one interpretation of Example 10 in Figure 3.

DETERMINISTIC REALIZATIONS OF UE-S					
Example	QPC	QC	Time in Years	Units Required for Replacement	UE-S
1.	1	10,000	1	1	0.0001
2.	1	5,000	2	1	0.0001
3.	1	2,000	5	1	0.0001
4.	2,000	5	1	1	0.0001
5.	200	10	5	1	0.0001
6.	1,000	10	5	5	0.0001
7.	125	100	4	5	0.0001
8.	1	100	1	5	0.0500
9.	2	100	1/2	5	0.0500
10.	1	50	1	100	2.0000

Figure 3

Example 10 also serves to illustrate the fact that UE-S is not a probability, i.e., UE-S may be greater than 1.0. In fact, it may be as large as 999.9999 according to the format of the field.

There is a more general path that the technician might have followed in order to estimate UE-S, namely, a probabilistic approach. If this were the case, he would have had to recognize a range of different possibilities and then assign probabilities of occurrence to each. After having done such, he would find UE-S by a calculation for which the first step consists of adding up the weighted expressions producing the average as a calculated "expectation" i.e., by taking the total sum over all possibilities of the individual terms

(Probability of Requirement) x (Required Number).

The second and final step consists of computing UE-S by dividing the above average by the base quantity of "part application years". This procedure qualifies as "more general" than the deterministic approach of the preceding paragraph for the reason that the former approach recognized but one possibility to which was assigned probability 1.0 so that all other possibilities were ruled out with assignment of zero probability. Examples a and b in Figure 4 depict two possible ways in which UE-S = 0.0001 might arise under a probabilistic approach where for simplicity the QPC, QC and Time parameters are fixed. Each of Examples a and b has the feature that the "average" number required per year is 1/2 and hence (UE-S) = (1/2) $\div$ (5,000) 0.0001. In either example the 1/2 could be interpreted as "one every other year" but, in the case of Example b, 1/2 purports to represent the average expected from requirements of less than 4 per year, in any year, wherein the probabilities for distinct requirements of 3, 2, 1, 0 are 1/20, 2/20, 3/20, 14/20 respectively, producing an average

$$1/2 = (3)(1/20) + (2)(2/20) + (1)(3/20) + (0)(14/20) = 10/20.$$

Example c illustrates a different phenomenon which probably is rare so far as actual practice in estimating UE-S is concerned. Nevertheless, it would be a possibility that the technician could see 75 units as his "average" number

PROBABILISTIC REALIZATIONS OF UE-S	
QPC = 10 QC = 500 Time = 1 year	
Example	Number of Units Required for Replacement
a. UE-S = 0.0001	1 unit with probability 1/2
	0 unit with probability 1/2
b. UE-S = 0.0001	3 units with probability 1/20
	2 units with probability 2/20
	1 unit with probability 3/20
	0 units with probability 14/20
c. UE-S = 0.0138	100 units with probability 1/4
	75 units with probability 1/2
	25 units with probability 1/4

Figure 4

of replacements but that he would also admit possibilities for ~~75~~ 100 and say 25 (rather than the more symmetric 50) as is the case in Example c. If he were to adopt this approach then his calculated average would be

$$68.75 = (100)(1/4) + (75)(1/2) + (25)(1/4)$$

to produce UE-S as

$$(68.75) \div (50,000) = 0.01375$$

which could then be recorded as 0.01, as 0.014, or as 0.0138 is shown in Figure 4. Indeed, 0.02 would be a possibility since it might be judged appropriate to round "up" to the next highest hundredth.

In the above examples whenever QPC is greater than 1, e.g., in Figure 4 where the part is installed ten times in the component, UE-S has in the discussion up to this point represented the average number of units which would be used to replace one of the ten units, i.e., one of the ten applications. Special care should be taken to note that this amounts to a tacit assumption that each of the ten units would be independently replaced. If, however, the part is of such a nature that if one of its applications in the component is replaced, some additional number of its applications (in this example up to nine) would also be replaced at the same time, then a different interpretation of UE-S is required. This refers to part applications for which the replacement unit is greater than unity, in which case UE-S denotes the average number of times the replacement unit or "set" is replaced. If, for example, the replacement unit equalled five in Figure 4 then each of the lines in Examples a and b should have the word "unit" replaced by "set of 5 units".

If the reader re-examines a) above, he will see that the actual definition of a numerical UE-S there contained does cover all of the cases which have been introduced into the discussion up to this point The discussion of a) may therefore be terminated with the following two remarks. First, if UE-S is to be an average it must be no smaller than 0.0001 since it is

required to be non-zero. Otherwise, b) prevails and the part is removed from consideration for shipboard stocking on account of the given component. Second, a more compact discussion of UE-S will be found below in Section 4 in company with precise definitions of "population" and "mean expected usage".

The entry "No Usage" for UE-S corresponds to one of the following conditions.

i) The part cannot be removed or replaced by ships force.

ii) There is an official written maintenance policy stating that the kind of maintenance necessary to remove or replace the item should not be performed by ships force.

iii) The item has for some other reason been excluded from consideration for shipboard stocking. For example, the item may itself be an "assembly" which is not to be stocked by the ship: the ship would be able to stock certain of its parts but not the "assembly" itself.

As is explained below under 32) there is an analogous field for the tender or repair ship level, namely UE-T which is designed to apply only to the cases where UE-S contains "NU".

15) Item code is a numeric code utilized to describe the general degree of on-board responsibility or control to be exercised over a given part. There are three basic codes: 1, 2, 3 which furthermore specify the Sections: A, B, C respectively, for the SNSL of the allowance list in which the part may be found. The three categories are defined by the Navy [6, p. 1-3] as follows.

a) Repair Part (Code 1). A repair part is an integral, manufactured and replaceable part (or assembly) of a piece of equipment or a component.

b) Operating Space Item (Code 2). An operating space item is a repair part, consumable item, or other item of supply, either a standard or a non-standard stock item, which is intended for immediate and direct end-use issue to an operating department of the ship for retention and use rather than an item intended for storage and inventory control by the Supply Officer.

c) Consumable Supplies (Code 3). Consumable supplies are those items which are consumed in use such as provisions (dry, chilled and frozen), ships store stock, clothing and small stores, medical and dental supplies, housekeeping supplies, ammunition (other than missiles and torpedoes), and repair materials such as gasket material, sheet metal, lumber or other bulk material from which items are fabricated.

In case a part satisfies more than one of the above definitions then there are separate records for the same part, one per Item code, each with an appropriate quantity (QPC) and CID included.

16) Unit of Allowance, UA, is contained in an alpha-numeric field designating the unit pack normally carried on board the vessel. The UA may not be the same as the Unit of Issue (UI) Field 19 as, for example, in cases of widely applicable manufactured or prefabricated items: the UA for nuts, bolts and screws is generally EA for "each" while the UI is commonly BX for "box". For items fabricated from bulk material such as gaskets or packing the UA is similarly often a "smaller" unit than the UI. The actual coding is given in Figure 5 which has been taken from [6, Appendix].

UNIT OF ALLOWANCE CODING*

Code	Unit
AY	Assembly
BA	Ball
BC	Batch
BE	Bale
BF	Board Foot
BH	Bunch
BK	Book
BL	Barrel
BN	Bundle
BO	Bolt
BR	Bar
BT	Bottle
BU	Bushel
BX	Box
C	Hundred
CA	Crate
CD	Card
CE	Cone
CF	Cubic Foot
CG	Cask
CI	Coil
CK	Cake
CL	Cylinder
CN	Can or Canister
CO	Container
CP	Hundred Pounds
CR	Cord
CS	Case
CT	Carton
CW	Hundredweight
CY	Cubic Yard
DK	Deck
DM	Dram
DR	Drum
DZ	Dozen
EA	Each
FO	Font
FT	Foot
GI	Gill
GL	Gallon
GM	Gram
GN	Grain
GR	Gross
GS	Glass

Code	Unit
HK	Hank
HP	Half Pound
IN	Inch
JR	Jar
KE	Keg
KG	Kilogram
KM	Kilometer
KT	Kit
LB	Pound
LF	Linear Foot
LG	Length
LN	Long Ton
LO	Lot
LR	Liter
LT	Light
LY	Linear Yard
M	Thousand
MB	Board Feet
MC	Cubic Feet
MF	Feet
MG	Grams
ML	Barrels
MM	Meters
MP	Pounds
MR	Meter
MS	Thousand Square Feet
MT	Measurement Ton
MY	Thousand Yards
NT	Net Ton
OT	Outfit
OZ	Ounce
PA	Paper
PC	Piece
PD	Pad
PG	Package
PH	Pouch
PI	Pitch
PK	Pack
PL	Pail
PN	Panel
PR	Pair
PT	Pint

Code	Unit
QR	Quire
QT	Quart
RA	Ration
RD	Rod
RE	Reel
RI	Ribbon
RL	Roll
RM	Ream
RN	Round
SA	Sack
SC	Section
SE	Set
SF	Square Foot
SG	Syringe
SH	Sheet
SI	Square Inch
SK	Skein
SN	Skin
SO	Shot
SP	Spool
SQ	Square
SR	Strip
ST	Stick
SU	Suit
SY	Square Yard
TB	Ten Barrels
TI	Tin
TN	Ton
TO	Troy Ounce
TU	Tube
US	U.S.P. Unit
VL	Vial
WG	Wine Gallon
YD	Yard

*Source: U.S. Navy Fleet Material Support Office Word Abbreviations 1 January 1962, p. 18.

Figure 5

17) Environmental code field contains "E" to indicate special storage requirements. Examples of items coded "E" include parts requiring carefully controlled atmospheric environments or special protection from shock.

18) Notes is an alpha-numeric field similar to Field 11 of the Component Data Master Record with the only difference being that the present field pertains to parts. The special designators are defined in the Table of Notes in the Appendix to the allowance list. In addition to their use for citing design changes, this field is employed to indicate certain operating space items (Cf. Field 15 Code 2) of different types including high cost items related to components having dual installations. For medical items the notes are used to represent certain precautions which are required as, for example, in storage or issue.

19) Unit of Issue, (UI), is employed for items having a UI different from UA: if the UI field is blank then UI = UA. [See Field 16] Figure 5 also serves to display the applicable codes for UI since these are the same as those employed for UA.

20) Part nomenclature is normally the Federal name of the item, possibly followed by modifiers. The noun name is usually not abbreviated, a "+" generally separates the noun name from its modifiers, but the actual contents of the field may be expected to vary in practice.

21) Part MEC code, MEC-P, is the part worth digit "p" of [3].

INSTALLABLE?	CRITICAL?	MEC-P
YES	YES	1
YES	NO	3
NO	YES	2
NO	NO	4

This field duplicates Field 45 of the present record.

22) Source code is contained in an alpha-numeric field, left justified with blanks following. It is used to indicate consumer source information, i.e., the manner of supply. Actual codes are assigned in accordance with [8]. Brief descriptions of the different series are as follows.

P Series: parts which are procured and are available in the supply system.

Code P: parts which are procured in view of relatively high usage and which are relatively simple to manufacture within the Naval establishment.

Code P1: parts which are procured in view of relatively high usage but which are very difficult, impractical or uneconomical to manufacture.

Code P2: parts for which little usage is anticipated but which are procured in limited quantity for insurance purposes. Such parts are difficult to manufacture, require special tooling not normally available within the Naval establishment, or require long production lead times.

Code P3: parts which are procured in accordance with the life expectancy of the part. Such parts are deteriorative in nature and may require special storage conditions.

M Series - Code M: parts capable of being manufactured within the Naval establishment and which are not procured. Such parts have no anticipated usage or relatively low usage, or possess restrictive installation or storage factors. Code "M" should not be applied to any item coded "P" for any of its applications nor to any items appearing in any Navy stock list. An item would be coded "M" only by the inventory manager having supply support for the item.

<u>A Series</u> - <u>Code A</u>: assemblies which are not procured but which are to be assembled within the Naval establishment prior to installation. At least one part within the assembly must be a stock numbered part coded "P".

<u>N Series</u> - <u>Code N</u>: parts which do not meet established criteria for stocking and which are normally readily available from commercial sources. Such parts are procured on demand in accordance with applicable procedures.

<u>X Series</u>: parts which are not procured on account of being normally impracticable for stocking, maintenance, or manufacture.

<u>Code X</u>: main structural members or similar parts which, if required, would suggest extensive repair. The need for a part, or parts, coded "X" normally results in a recommendation for complete overhaul or retirement of the component from service.

<u>Code X1</u>: parts for which procurement of the next larger assembly coded "P" is justified, e.g., an internal detail part, such as a welded segment inseparable from its assembly, a part which must be machined and installed with other parts in a matched set, or a part of an assembly which, if required, would suggest extensive reconditioning of the assembly.

<u>Code X2</u>: parts which are not procured for stock but which may be acquired for use through salvage. Activities requiring such parts are to attempt to obtain them from salvage. If they are not obtainable from salvage, then such parts are to be requisitioned through normal supply channels with supporting justification. Repeated requests may justify changing the source code to a "P" series code.

U Series - Code U: parts which are not of supply or maintenance significance such as installation drawings, diagrams, instruction sheets, field service drawing numbers, and parts which should not or cannot be procured or manufactured. This is an optional code.

23) Maintenance code is a two-part code used to designate appropriate maintenance echelons.

a) Position 114: the lowest maintenance echelon capable of installing the part in the component where the lowest of all is the vessel itself.

b) Position 115: the lowest maintenance echelon capable of manufacturing, assembling or testing the part prior to installation.

Maintenance codes are assigned in accordance with [8] as follows.

CODE	MAINTENANCE ECHELON for NAVY MATERIAL
F	Activity to which equipment is assigned, e.g., the vessel.
T	Tender or repair ship.
O	Overhaul activity.
E	Specialized repair facility.
B	Specific maintenance requirements not applicable (Optional).

The significance of "optional" above related to Code "B" is that a blank may be found in place of "B" to indicate that no one of "F", "T", "O", or "E" applies.

24) Recoverability code is used to designate supply system recoverability. Specifically, this code reflects the recoverability characteristics of items removed from components at the time of maintenance, repair or overhaul. Actual codes are assigned in accordance with [8] as follows.

Code R: parts which are economical and practical to repair. Replacements are obtained from the supply system or on an exchange basis, if and when practicable i.e., a part may be lost or damaged beyond recognition, or the inventory manager may not require such exchange.

Code S: parts which are economical and practical to salvage and which may be placed in "ready for issue" condition by cleaning, replating, adjusting, replacement of bearing or bushing, etc. Parts coded "S" may contain parts or materials which are usable, valuable, or critical, and which may be placed in the supply system for issue.

Code C: parts which are consumable (expendable), i.e., parts which are neither reparable nor salvageable. This is an optional code so that a blank may appear instead of "C" to indicate that neither of "R" or "S" applies.

25) Quantity installed per Component, QPC, is a field which overall may be quite variable with the following range of possibilities for representing the quantity or amount installed in one component.

a) An integer quantity of units of allowance in which case the field is numeric.

b) A decimal quantity of units of allowance in which case Position 119 contains a decimal point (.) so that QPC is given to 1 D as xx.x.

c) The code "AR" right justified with two initial blanks to designate "as required". (In this case Field 43,

AQ-RU, will be blank following an Optimum COSAL calculation and Field 55, AQ-UA, will have "AR" as does the present Field 25.)

26) Replacement Unit, RU, is defined as an integer multiple of the UA which is required as a minimum replacement to repair, maintain or overhaul the component. As such, it is a function of both the SN and the CID; in other words, the RU for a specific SN may vary over different CID's. If RU = 4 for a part having UA equal to "Each", then a "set" of four would be required as the smallest quantity of the SN sufficient for use on account of the CID. In such a case a single UA of the part would not be replaced independently, instead there would always be concurrent installation of four.

There are three possibilities for the RU field.

a) The field represents an integer quantity greater than unity. This is the case where there is a non-trivial RU > 1 .

b) Position 121 does not contain X and the field does not represent an integer quantity greater than unity. For this case it will be convenient to define RU = 1 . This means that in case the field contains zeros, blanks, or whatever providing only that 189 does not contain X, then RU = 1 .

c) Position 121 contains ' X" in which case RU is not applicable and the field is being employed to record a numeric X-factor in Positions 122-124. Here, AQ-RU is blank and AQ-UA is the numeric portion of the present field which equals the mandatory value.

On account of the convention expressed in b) it will be convenient to employ RU with the understanding that $RU \geqq 1$.

27) Manufacturers code is the Federal numerical manufacturers 5 digit code.

28) Reparable Return Rate is a quantity expressed to 2D, i.e., as x.xx but the decimal point is not written into the record. This rate is defined as the fraction of the total failures of an item which require that the item be returned to a higher maintenance echelon in lieu of repair at point of failure. These estimates are made only for the shipboard level. A reparable return rate is normally assigned only if the Recoverability Code, Field 24, equals "R". Furthermore, it is usually true that the UE-S field has to be different from "NU" in order that there be a reparable return rate assigned. The following examples will illustrate the meaning of this datum.

a) Items which have a Recoverability Code of "C" and have no reparable return rate have this field blank.

b) If for three out of every five failures of the item it is returned to the tender or to a higher echelon for repair, then the reparable return rate equals 0.60.

c) When the vessel cannot repair the part on board and must send all such failed units to the tender, the reparable return rate is 1.00 indicating 100 percent must be returned.

d) When the part can invariably be repaired at the ship level, the reparable return rate entry is 0.00 indicating that no units are returned to the tender.

e) A sealed component which is only to be repaired by the contractor has a reparable return rate of 1.00 again indicating total return of all failed units from the operational echelon to the tender.

29) Wearout Rate is a quantity expressed to 2D, i.e., as x.xx but the decimal point is not written into the record. This rate is defined as the fraction of times the part cannot be economically repaired. It is thus equivalent to the "condemnation rate" or "strike rate". Wearout Rates are normally given only for items with Recoverability Code, Field 24, equal to "R". Furthermore, it is usually true that UE-S, Field 14, is different from "NU" in order that a Wearout Rate be assigned. The following examples will illustrate the meaning of this datum.

a) Items which have a Recoverability Code of "C" and whose wearout is 100% ordinarily have Wearout Rate blank. However, as an optional feature the rate may in this case be expressed as 1.00.

b) When there are 3 wearouts per 4 failures of the item the wearout rate equals 0.75.

c) When invariably the part can economically be repaired, then the wearout rate is 0.00. In the contrary case, a rate of 1.00 means that the part cannot economically be repaired.

30) Type of Repair Activity is used to reflect the maintenance policy for each reparable item. The actual code indicates the first echelon at which it is possible to accomplish the actual repair of the item. Specific codes are as follows.

CODE	FIRST REPAIR ECHELON
F	Activity to which equipment is assigned, e.g., the vessel.
T	Tender or repair ship.
O	Overhaul activity.
E	Specialized repair facility.
C	Contractor and certain designated Navy facilities.

Note that except for "C", this field duplicates the first entry in the maintenance code, Position 114 of Field 23. The present code is normally assigned to each part having a Recoverability Code "R". Furthermore, such an item would usually have one of UE-S or UE-T different from "NU".

31) Service Life, if applicable, is used to express the recommendation as to when the item should undergo repair, recalibration, overhaul, or other scheduled preventive maintenance requiring removal and replacement of the installed part. Service life is expressed in terms of operational hours.

32) Usage Estimate-Tender, UE-T, denotes a field completely analogous to Field 14) wherein one moves from the former cases of "shipboard level" and "ships force" to "tender or repair ship level" and "tender or repair ship force", respectively.

The original instructions called for this field to be significant only for those parts for which Field 14) contained "NU"; i.e., UE-T's should be supplied only for those parts for which UE-S = NU. Therefore, there would be only two possibilities for the UE-T field.

a) A non-zero estimate of average usage at the tender or repair ship level.
b) An entry "NU" to denote "No Usage".

33) ECN Table Contents - Column 1 is used to record entries in Equipage Category Number - Allowance Parts Lists: ECN-APL's. This means that this field is of relatively limited interest for the present paper -- it is blank for admissible CID's. In effect, the use of this field is limited to items for which the allowance quantity is established by decree. In case the present field is applicable, it contains the entry to be found in the first column of the row for the SN in the ECN-APL table designated by the CID.

There are three possibilities.

a) An integer quantity of units of allowance in which case the field is numeric.

b) A decimal quantity of units of allowance in which case the central position contains a decimal point so that the quantity is given to 1 D as x.x.

c) The code "AR" right justified with one initial blank to designate "requisition As Required".

In case Column 1 is indeed the applicable column for this vessel-CID combination, this will be designated by "1" in Position 176, the QC field. See 41) below.

34)	ECN Table Contents - Column 2	These fields are entirely analogous to Field 33. However, note that Field 40 below has four positions.
35)	- Column 3	
36)	- Column 4	
37)	- Column 5	
38)	- Column 6	
39)	- Column 7	

40) ECN Table Contents - Column 8 is similar to each of Fields 33-39 inclusive except that the present case has four positions with three possible types of entry (cf. QPC, Field 25).

a) An integer quantity of UA.

b) A decimal quantity of UA xx.x with the decimal point (.) written in Position 171.

c) The code "AR" right justified with two initial blanks to designate "requisition As Required".

41) Quantity of Component installed, QC, is the same as in Component Data Field 9 except for the case of ECN-APL's. For this latter case, Position 176 contains the ECN-APL Column number from Component Data Field 10.

42) MEC Data is a field which has been made available for use in printing MEC information. At present this field is not being utilized for this purpose. Prior to an Optimum COSAL calculation the field contains the MEC class code for the CID taken from Component Data Field 8.

43) Allowance Quantity in Replacement Units, AQ-RU, is the quantity determined and written during the Optimum COSAL calculation. As is mentioned in Footnote 1 for Figure 2, the present AQ-RU is to be carefully distinguished from AQ-UA, the "piece" quantity actually printed in the allowance list. The present field, AQ-RU, is the more basic for our purposes. Allowance list calculations by the Optimum COSAL model are performed only for admissible CID's and then in terms of AQ-RU. As is explained below, a part is an allowance list candidate if and only if following an Optimum COSAL calculation, AQ-RU is not blank. That is, if AQ-RU = 0 then the field contains 0000 . If AQ-RU is blank as distinct from 0000 then the part was never considered competitively for stocking by the procedures of the Optimum COSAL model. If in this latter case AQ-UA is non-zero, then this quantity was determined by decree (table look-up) and not by the optimization model.

For the case of parts with Field 15, Item code, containing "1" the aggregate AQ-UA (which is printed in Section A, Part III, SNSL) represents [6, p. 4-2]

> "the recommended high limit (...the mandatory quantity...the total of on hand and on order quantities...) for that particular item, unless unanticipated usage or other factors necessitate the ship exceeding that quantity."

For the case of parts listed in Sections B and C, Part III, SNSL (Item codes of "2" and "3" respectively) the AQ-UA is "not a mandatory maximum on-board quantity" [6, p. 4-2].

44) Component-Equipment MEC code, MEC-CE, is the same as in Component Data Field 12.

45) Part MEC code, MEC-P, duplicates Field 21 of the present record described above.

46) Ordinal Locator = MEC code, MEC, is the code associated with the pCE - septuplet defined in [3]. (Cf. also Component Data Field 8.) The actual contents of the field are numeric: one of 0116, 0115, . . . , 0088 if p = 1; one of 0087, 0086, . . . , 0059 if p = 3; one of 0058, 0057, . . . , 0030 if p = 2; and one of 0029, 0028, . . . , 0001 if p = 4.

47) Inverse MEC code = 10,000 - MEC, MEC-INV, is an arithmetic inverting of MEC for use in sorting operations where it is convenient (internal to the computer) to have the higher military worth represented by the lower arithmetic quantities.

48 ff) Computational Fields are displayed below in Figure 13.

3. Allowance list format.

The present section describes the format of a published "Optimum COSAL", i.e., an Optimum Coordinated Shipboard Allowance List. These are the allowance lists of concern for the present series of papers. It will be found that by utilizing definitions contained in the preceding sections plus those given below it will be easy to define exactly what makes up an allowance list. The discussion will proceed in terms of the USS GEORGE WASHINGTON (SSB(N) 598) Optimum COSAL [6] for which the general format is depicted in Figure 6. The entire allowance list for this single vessel is contained in 21 rather large binders (11 1/2" x 12" x 2 1/2", up to 800 pages, and up to 9 pounds each), each binder containing one volume. Another way of expressing the magnitude of the data represented by Figure 6 for a single ship is to state that it fills about 17,000 pages. Similarly, it may be noted that one Optimum COSAL will itself completely fill a five-foot shelf, which shelf should be a sturdy one since it would be loaded with 21 books, each a foot high, with total weight just under 200 pounds.

OPTIMUM COSAL FORMAT USS GEORGE WASHINGTON (SSB(N) 598)
<u>1 Volume</u> Introduction Appendix Summary of Effective APL's Part I: Index Section A Index Section B
<u>12 Volumes</u> Part II: Allowance Parts Lists - APL's
<u>4 Volumes</u> Part III: Stock Number Sequence Lists - SNSL's Section A: Repair Parts Section B: Operating Space Items Section C: Consumable Supplies
<u>4 Volumes</u> MEC SNSL's

Figure 6

The first volume contains general as well as specific explanatory and reference material. The Introduction consists of four chapters.

Chapter 1. Organization and Functions
2. (Explanation of) Index
3. (Explanation of) APL's
4. (Explanation of) SNSL's

The Appendix consists of four parts.

1. General Index of Material on ECN-APL's is a table designed to permit one to determine the general series of ECN-APL's containing an individual equipage item. The table is sorted on part nomenclature; for each part nomenclature there is recorded a sufficient number of significant positions (seven: 10-16 of Figure 1) of the applicable CID's. For example, entering with "soldering iron-electric" yields 2-67003 and 2-92001. Corresponding to the first of these is one applicable ECN-APL, 2-670034001 representing "Tools-hand electronic repair". On the other hand, to the second, namely 2-92001 there turn out to correspond 36 applicable ECN-APL's since this is the series listing tools stowed in the tool room. Since the material on any ECN-APL is listed alphabetically, it is easy to scan one ECN-APL or even an entire series in order to determine the quantity authorized for a given vessel.

2. List of Abbreviations contains two parts.

Part I. Abbreviation to word(s)/phrases
Part II. Word to abbreviation

3. Table of Notes defines the symbols employed in Component Data Field 11 and Part Data Field 18, Figures 1 and 2, respectively, of the present paper.

4. Table of Military Essentiality Codes consists of a brief description of the Polaris MEC system of [3].

The Summary of Effective APL's, SOEAPL, is a listing of all applicable CID's for the vessel. There are three entries per CID.

a) CID "number", i.e., Component Field 3.

b) Date of publication.

c) Number of pages in the printed APL.

The sequence of entries in the SOEAPL is as follows.

1. Admissible CID's
   a. Preliminary CID's wherein the initial two positions of the code contained "P+".
   b. Numeric CID's.
2. Inadmissible CID's: ECN-APL's in normal collating sequence.

Notice that the above is different from normal collating sequence on CID which would inter-mix 2 within 1; e.g., the ECN-APL's 1+... in 2 would precede CID's 10... in 1.

Part I of the allowance list, the Index consists of two listings for the same data sorted into two different sequences. The data contained in the printed Part I consists of certain fields from the Component Data Master Records (Figure 1) as shown in Figure 7. As is also shown in Figure 7, the two sequences are formed by interchanging major/minor sorting fields and then printing the same data.

a) Index Section A: Primary sort on CID nomenclature.
Secondary sort on SA nomenclature.

b) Index Section B: Primary sort on SA nomenclature.
Secondary sort on CID nomenclature.

OPTIMUM COSAL FORMAT PART I - INDEX	
PRINTED ENTRIES	
Component Data Master Record Field Number	Contents
1	Hull type
2	Hull number
3	CID
4	Program Support code
5	SA[1/]
6	CID nomenclature
7	SA nomenclature
8	MEC
9	QC
10	ECN-APL column number
11	Notes
15	Security Classification
SEQUENCE FOR PRINTING	
INDEX SECTION A:	Primary sort on Field 6 Secondary sort on Field 7
INDEX SECTION B:	Primary sort on Field 7 Secondary sort on Field 6

[1/] True SA codes are not printed. In case Field 5 contains a CUD then this code is printed immediately below the CID code.

Figure 7

The only remaining observation to be made is that the printed Index always shows a date of generation as consistent with the fact that the basic records change with time.

The 12 volumes which make up Part II of the allowance list consist of Allowance Parts Lists, APL's, bound together into binders. The sequence in which the APL's appear in Part II is the same as for the SOEAPL. Figure 8 summarizes the data contained in Part II and also the sequence for binding. It is to be noted that there is one APL per CID code so that they do not vary with SA. Furthermore, the APL lists the installed parts by stock number and part nomenclature and lists considerable additional technical information as well. The actual APL's making up Part II are the same individual documents used to make up Part II of a regular COSAL.

The 4 volumes which make up Part III of the allowance list consist of Stock Number Sequence Lists, SNSL's, in three parts according to Repair Part Master Record (Figure 2) Field 15: Item Code.

Section A: Repair Parts . . . . Item Code 1
Section B: Operating Spare Items . . . . . Item Code 2
Section C: Consumable Supplies . . . . . . Item Code 3

The exact contents are displayed in Figure 9. Section A is contained in three volumes while Sections B and C together make up a relatively thin fourth volume. Entries for SN's are printed in each section in sequence by SN and lines within SN in order by CID. It is particularly worthy of note that the zero AQ-UA'S are printed in the SNSL. That is, the SNSL displays the full range of possible demand rather than simply the range of items stocked with non-zero AQ-UA. On the very last page for Section A, there are printed the following grand totals.

OPTIMUM COSAL FORMAT

PART II - APL's

CONTENTS

1. Part II is a collection of APL's.

2. Each APL is a technical document falling into one of two classes.

   a) It contains detailed information on a particular component or equipment in which case it is identified by an admissible CID code.

   b) It consists of a list of items of equipage (e.g., binoculars, tools, etc.), or certain material requirements for particular systems (e.g., steering and diving systems), or general requirements (e.g., hose and hose fittings), or other technical information (e.g., reference material). In all such cases the APL is identified by an inadmissible CID code.

SEQUENCE OF APL's

The sequence in Part II is according to CID code in agreement with the order within the "Summary of Effective APL's".

1. Admissible CID's in normal collating sequence.

   a. Preliminary CID's: P + ...

   b. Numeric CID's

2. Inadmissible CID's in normal collating sequence.

Figure 8

OPTIMUM COSAL FORMAT

PART III - SNSL's

PRINTED ENTRIES

SNSL Entry	Contents (Repair Part Master Record Field)
1. Hull Type	Field 1: Hull type
2. Hull Number	Field 2: Hull number
3. Stock Number	Field 6: Supply Support code
	Field 7: SN
4. Nomenclature	Field 20: Part nomenclature
5. Application Code 1/	Field 4: CID
6. Unit of Allowance	Field 16: UA
7. Allowance Quantity	Section A: Sum of AQ-UA over all CID's. A single entry.
	Section B: Multiple entries, one line per CID.
	Section C: A single entry per vessel.
8. Notes	Field 18: Notes
9. Code S 1/	Field 22: Source code
10. Code M 1/	Field 23: Maintenance code
11. Code R 1/	Field 24: Recoverability code
12. MEC Code 1/	Section A: Field 46: MEC
	Section B: Field 42: MEC Data (class code)
	Field 45 = Field 21: MEC-P
13. Remarks (Section A only)	Protection Level: most significant five digits of achieved protection level.
	Override: an asterisk (*) to indicate AQ-RU = 1 on account of MEC greater than 100.

SECTIONS

Section A: Item Code, Part Data Field 15: Code 1

Section B: Code 2

Section C: Code 3

SEQUENCE WITHIN SECTIONS

Primary Sort: SN (not including Supply Support code.)

Secondary Sort: CID

1/ Not applicable to Section C. Multiple entries are printed, one line per CID.

Figure 9

a) Price: total extended price in dollars over all AQ-UA in Section A.

b) Range: at present this is generated from the grand total for range through MEC 59 as shown below in Figure 1C ^his means that the count actually tallies the distinct MEC, SN pairs for which there is at least one CID with non-zero AQ-UA. (Cf. Figure 10 below.)

c) Cube: total extended cube in cubic feet over all AQ-UA in Section A.

d) Price Override is the total extended price in dollars over all AQ-RU in MEC 115-101 inclusive which were stocked in quantity of one RU per CID on account of the MEC override. (These are the items which otherwise would not have been stocked on the allowance list due to low expected usage, large cube, or high price, etc.)

e) Range Override is actually a sub-total within b) above to count the number of times the override was invoked.

f) Cube Override is the total extended cube which resulted on account of the MEC override.

The last 4 volumes are unique to the Optimum COSAL; these are the Military Essentiality Class or MEC SNSL's summarized in Figure 10. Three sub-totals and three corresponding cumulative (over MEC) totals are printed at the end of each MEC group. As implied by their name, these volumes represent SNSL's compiled for each MEC. The major innovation is that these volumes display the individual allocations of AQ-UA by CID; in Part III, Section A there is only a single AQ-UA per SN representing the total for all CID's.

OPTIMUM COSAL FORMAT MEC - SNSL's
PRINTED ENTRIES 1. Same data as contained in Section A of SNSL except that each AQ-UA is printed separately as computed, one line per CID. 2. At end of each MEC group there are sub-totals and cumulative totals as follows. SUB TOTAL PRICE = Total of extended price in dollars over allowance quantities for the MEC code. SUB TOTAL RANGE = Number of distinct SN's [1/] stocked with non-zero AQ-UA for the MEC code. SUB TOTAL CUBE = Total extended cube in cubic feet over allowance quantities for the MEC code.
SEQUENCE Primary sort is on MEC in inverse order: 116, 115, ..., 59.
SEQUENCE WITHIN MEC Primary sort on SN Secondary sort on CID

[1/] In case an SN appears with non-zero AQ-UA on more than one CID for a given MEC, it is counted only once in this range count. In case an SN appears with non-zero AQ-UA on more than one CID for different MEC, it is counted more than once in the cumulative range; this latter is range accumulated over MEC.

Figure 10

4. Allowance list candidates.

An allowance list candidate is a part which leads to admissible arithmetical input to an allowance list model. Such a part actually becomes a candidate or competitor for the stowage space and budget available for allowance list items. A part listed on an ECN-APL is not a candidate in this sense; its allowance quantity, AQ, has been determined in advance and can be found by table look-up. Thus, instead of being a competitor, an ECN-APL part has the role of a pre-emptor which reduces the total amount of stowage space available for the allowance list candidates. The remaining requirements are perhaps more obvious. It is required that an allowance list candidate be wearable, that it be possible for the ships force to replace it, and that it actually be an installed part. Straightforward as all this may seem, the actual definition given below may appear complex at first meeting but this is mainly on account of vagaries of parts data. One additional equivalent definition is given and then the remaining portion of this section is devoted to development of various properties of allowance list candidates.

a. Definition of an allowance list candidate.

DEFINITION. An allowance list candidate for a particular vessel is a part for which there exists an admissible (SN, CID) record. By definition this means that in the Repair Part Data Master Record File (Figure 2) for this vessel there exists a record corresponding to this (SN, CID) pair satisfying the following conditions.

a) Field 4 of the Part Record, CID, represents an admissible CID, i.e., by definition it satisfies exactly one of the following conditions:

i) Position 12 does not contain "+",

ii) Positions 11, 12 contain "P", "+", respectively.

b) Field 15, Item code, contains "1".

c) Field 46, MEC, contains one of "0116", "0115",...., "0059".

d) Field 21, MEC-P, or the equivalent Field 45 contains "1" or "3".

e) At least one of the following conditions is satisfied:

i) Field 30, Type of Repair Activity, contains "F",

ii) Field 23, Maintenance code, contains "F" in Position 114.

f) Field 25, QPC, does not contain "A", "R" in Positions 119, 120, respectively.

g) Field 26, RU, does not contain "X" in Position 121.

h) Field 14, UE-S, does not contain "N", "U" in Positions 71, 72, respectively.

Condition a) has the effect of requiring that the part be a "technical part" installed in an admissible parent component-equipment. Condition b) requires that the part be designated a "repair part". Conditions c), d) and e) are purposefully redundant: the idea here is not only to check that the part be installable by ships force but to verify that the MEC codes are consistent. Condition f) eliminates parts with non-numeric populations: if their QPC is "as required", we view them as actually not being installed and so omit them from subsequent arithmetical processing. Condition g) eliminates parts whose AQ's are determined by "X-factors". The final condition h) is imposed in order to restrict attention to wearable parts, i.e., those which have some positive probability of being used by ships force, i.e., it eliminates parts having "no usage".

There is a convenient way to determine "after the fact" whether or not a part is an allowance list candidate. This is based on the following result whose "proof" follows from the nature of the Optimum COSAL computer program [5].

THEOREM. A part application is an allowance list candidate if and only if Field 43, AQ-RU, is not blank after completion of the Optimum COSAL calculation for the Repair Part Data Master Record File.

This result is of particular significance for "post-audit" calculations where various analyses are to be performed in order to evaluate a particular allowance list model. In such a case it would of course make little sense to consider all records; instead, we would ordinarily restrict our attention to the admissible (SN, CID) pairs which are the only records to which the optimization model was actually applied.

Looking ahead to post-audit analyses for allowance list calculations and indeed, even considering prior analysis of input data, it is convenient to have the following conventions.

TERMINOLOGY. To each admissible (SN, CID) record there corresponds an admissible SN, namely, the contents of Field 7. Conversely, to a given admissible SN there may correspond several admissible (SN, CID) records.

To each admissible SN there corresponds an admissible Item Number, admissible IN, defined as follows.

a) If Field 7 contains an FSN, then the corresponding IN is the FIIN, i.e., the contents of Positions 31-38.

b) Otherwise, if Field 7 does not contain an FSN, the corresponding IN is the SN, i.e., the entire contents of Field 7.

Conversely, in case a) to any one admissible IN there may correspond several admissible SN's. (This requires that one FIIN be associated with different FSC's.)

The above terminology re-states the association of "admissible (SN, CID)" with "admissible part application" inherent in the definition of an allowance list candidate. One additional step is taken, namely, to associate "admissible part" with "admissible IN". While "part application" links the part to a specific parent component, the "IN" is independent of any particular CID and therefore relates to a distinct physical entity.

b. General numerical data.

It will be convenient at this point to introduce terminology and fix notation for additional data which are developed for allowance list candidates. These are data required as input for numerical calculations within the general framework of the Optimum COSAL models and hence they are not generated for part applications other than allowance list candidates.

Figure 11 displays terminology and notation for the range of general data wherein the order of arrangement is alphabetical on data processing notation within each of I, II and III. These data are "general" in the sense that certain of them (e.g., Nos. 7 and 9) are specialized for particular cases as will be described in the following Sub-section c. The general data will now be discussed in a logical order of development slightly out of sequence with the manner in which they are arranged in Figure 11 for ready reference.

1) Population data, POP-RU or N. represents the frequency of installation of the part-application for the vessel in units of the RU. It is to be recalled that RU is taken to be unity for an allowance list candidate unless it is specifically written as greater than unity, i.e., even though

GENERAL TERMINOLOGY AND FIXED NOTATION
ALLOWANCE LIST CANDIDATES

	DATA PROCESSING NOTATION FOR LISTINGS	ALGEBRAIC NOTATION	TERMINOLOGY - DEFINITION
I. Basic Data	1. AQ - RU	n	Allowance quantity in replacement units (RU).
	2. CUBE - RU	c	Cube in cubic feet per RU.
	3. MEAN - 02	m	Mean usage for ship: RU per 02 months.
	4. MEC	w	MEC code: "w" for "worth".
	5. POP - RU	N	Population in RU: number of opportunities for usage.
	6. PRICE - RU	p	Price in dollars per RU.
II. Cost Data	7. COST - HOLDING	A	Holding Cost: penalty per RU stocked in excess of number demanded.
	8. COST - SHORTAGE	B	Shortage Cost: penalty per RU demanded in excess of number stocked.
III. Functions	9. FN - CUBE	g(c)	Scaled CUBE - RU value.
	10. FN - HOLDING	a(s)	Expected number RU overstocked $a(s) = \sum_{i=o}^{s} (s-i)P_i$ if s = AQ - RU.
	11. FN - LOSS	L(s)	$L(s) = A \cdot a(s) + B \cdot b(s)$ if s = AQ - RU.
	12. FN - MEC	f(w)	Scaled MEC value.
	13. FN - PRICE	h(p)	Scaled PRICE - RU value.
	14. FN - PROB	P_i	P_i = Prob. usage i RU where $i = 0, 1, 2, \ldots, n, \ldots$.
	15. FN - SHORTAGE	b(s)	Expected number RU understocked $b(s) = \sum_{i=s+1}^{\infty} (i-s)P_i$ if s = AQ - RU .
	16. PROT - ACH	C_n	Achieved Protection Level $C_n = \sum_{i=o}^{n} P_i$ where n = AQ - RU .
	17. PROT - DEV	t	Developed Protection Level(threshold) $t = \text{Max}\ [0, B/(A+B)]$

Figure 11

Field 26 may contain 0000, blanks, etc. Then we may write

$$N = \text{POP-RU} = [(\text{QPC}) \cdot (\text{QC})] / (\text{RU}) .$$

By its definition, N should be an integer. In case it were to turn out otherwise, we would conclude that there were errors in input and as an expedient we would use the next highest integer as N. In other words, *if* $[(\text{QPC})(\text{QC})] / (\text{RU})$ *is not an integer there is an error in one or more* of QPC, QC, RU but we "round up" to force the computed value of N to be a positive integer.

2) Mean expected usage, MEAN-02 or m, represents a population weighted average usage by the vessel during 02 months in units of the part-application RU. In terms of the data processing notation the time period is specified in months. Whenever "m" is used, it is used alone with the understanding that the time period is as has been specified in context. For example

$$\text{MEAN-}\underline{02} = (\text{POP-RU}) \cdot (\text{UE-S}) \cdot (\underline{\ 2}/12),$$
$$\text{MEAN-}\underline{03} = (\text{POP-RU}) \cdot (\text{UE-S}) \cdot (\underline{\ 3}/12),$$
$$\text{MEAN-}\underline{12} = (\text{POP-RU}) \cdot (\text{UE-S}) \cdot (\underline{12}/12).$$

3) MEC, Cube and Price data are handled both in their raw or "actual value" forms and in their corresponding "scaled" forms as desired for calculation. Actual procedure consists simply of employing the usual notion of a mathematical function as should be evident from the following layout.

Table	Argument	Table Entry
MEC	w	f(w)
CUBE-RU	c	g(c)
PRICE-RU	p	h(p)

Another way of expressing the above for the case of cube data is to say that g(c) is the value of the scaling function for cube per replacement unit at the place c .

4) Cost data are required in order to be able to formulate a "loss function" for which a minimum is sought *in an allowance list model*. As indicated in Figure 11 two numbers are used: A and B . These may be considered to be determined for each allowance list candidate; there may be common values for all candidates or one could determine the pair A, B differently for different candidates.

a) Unit Holding Cost

A = penalty per RU stocked in excess of number demanded.

b) Unit Shortage Cost

B = penalty per RU demanded in excess of number stocked.

We require that not both A and B are zero. It is of course required that both of A and B are measured in the same units.

5) Demand prediction data are based on a probability distribution $\{P_i\}$, $i = 0, 1, 2, \ldots$ with mean equal to m . As explained just above in 2), there is a specific time period understood, e.g., two months in which case m represents MEAN-02. The definition of the term P_i is as follows.

P_i = Probability of exactly i replacement units (RU) being demanded for ships force use during 02 months.

We must have $P_i \geqq 0$ for each i and furthermore $\sum_{i=o}^{\infty} P_i = 1$. By definition, m is the mean of the distribution $\{P_i\}$, i.e.,

$$m = \sum_{i=o}^{\infty} i \cdot P_i .$$

Given $\{P_i\}$ it is a simple matter to compute a holding function whose value a(s) equals the expected number of RU overstocked in case the allowance

quantity, AQ-RU, equals s . In this way, there is defined a function on $s = 0, 1, 2, \ldots$ having values

$$a(s) = \sum_{i=0}^{s} (s - i) \cdot P_i \, .$$

Proceeding in the same fashion, it is easy to write down the expected number of RU understocked in case AQ-RU equals s . This is the shortage function b defined for $s = 0, 1, 2, \ldots$ having values

$$b(s) = \sum_{i=s+1}^{\infty} (i - s) \, P_i \, .$$

6) A loss function, L(s), is defined in terms of the data just above in 4) and 5). It is more accurate to describe L as an expected loss function since its values equal mathematical expectations, i.e.,

$$\begin{aligned} L(s) &= A \cdot a(s) + B \cdot b(s) \, , \\ &= A \cdot \sum_{i=0}^{s} (s - i) \cdot P_i + B \sum_{i=s+1}^{\infty} (i - s) \, P_i \, . \end{aligned}$$

7) Protection levels are defined relative to a specific allowance quantity AQ-RU = n . The first of these is called the achieved protection level, PROT-ACH,

$$C_n = \sum_{i=0}^{n} P_i \, .$$

This is simply the cumulative probability through n for $\{P_i\}$ and in context it represents the probability that demand will not exceed supply. Specifically, if AQ-RU = n then C_n represents the probability that the number of RU demanded for ships force use during the specified time period (e.g., two months) will not exceed n .

A second protection quantity, the developed protection level will be defined here for convenience of reference. Its interpretation and use along with justification for its nomenclature will be given elsewhere. It can be established as a theorem that an "optimum" AQ-UA = n results from the calculation

$$n = \min_s \{C_s \geqq B/(A + B)\} .$$

(This result will be discussed in a subsequent paper of the present series.) The above result establishes $B/(A + B)$ as a threshold to be surmounted by the cumulative probability C_s. Since this latter is non-negative, an equivalent threshold results from replacing any negative $B/(A + B)$ by zero. In this way we define

$$t = \mathrm{Max}[0, \; B/(A + B)]$$

so that $0 \leqq t \leqq 1$ on account of $A + B > 0$. We label t as a <u>developed protection level</u> since by association it may itself be regarded as a cumulative probability.

c. <u>Special Optimum COSAL numerical data.</u>

The implementation to date by the Navy in the Optimum COSAL Program has been based on certain special cases for some of the data displayed above in Figure 11. Actual cases are summarized below in Figure 12.

1) <u>Negative binomial probability distributions</u> have been selected as the $\{P_i\}$ for use in calculations. This choice was made on the basis of Project studies to be reported elsewhere. General properties for this family of distributions are given in Feller [4] and, for example, in the review article by Bartko [1]. In our notation, $\{P_i\}$ can be generated formally via

$$\{q - (q - 1)\}^{-k}$$

where $k > 0$ and $q > 1$ in which case P_i is the coefficient of the $(i + 1)$-st term. The mean is

$$m = k(q - 1)$$

and the variance is $q \cdot m$. The pair, m and qm, suffice to provide a complete description of the distribution. There exist various ways of computing the terms P_i. Starting with (k, q) one has

SPECIAL CASES - OPTIMUM COSAL PROGRAM
TERMINOLOGY AND NOTATION
ALLOWANCE LIST CANDIDATES

	DATA PROCESSING NOTATION FOR LISTINGS	ALGEBRAIC NOTATION	TERMINOLOGY-DEFINITION
I. Negative Binomial Probability Distribution	1. FN-QUE	$q = q(m)$	q = variance-to-mean ratio, $q > 1$.
	2. FN-KAY	k	$k = m/(q-1)$.
	3. FN-PROB [1/]	$P_i = P_i(m, q)$	P_i = i-th term of neg. bin. prob. dist. with mean m and variance $q \cdot m$.
	4. PROT-ACH [1/]	C_n	Achieved Protection Level $C_n = \sum_{i=o}^{n} P_i$ where n = AQ-RU.
II. Scaling Parameters	5. ALPHA-MEC	α	MEC multiplier, $\alpha > 0$.
	6. LAMBDA-CUBE	λ_c	CUBE-RU multiplier, $\lambda_c \geqq 0$.
	7. LAMBDA-PRICE	λ_p	PRICE-RU multiplier, $\lambda_p \geqq 0$.
III. Cost Functions	8. FN-MEC [1/]	$f(w)$	$f(w) = \exp\{-\alpha(116-w)\}$, [2/] $\alpha > 0$.
	9. FN-CUBE [1/]	$g(c)$	$g(c) = \lambda_c \cdot c$, $\lambda_c \geqq 0$.
	10. FN-PRICE [1/]	$h(p)$	$h(p) = \lambda_p \cdot p$, $\lambda_p \geqq 0$.
	11. COST-HOLDING [1/]	A	Holding Cost $A = \lambda_c \cdot c + \lambda_p \cdot p$.
	12. COST-SHORTAGE [1/]	B	Shortage Cost $B = \exp\{\alpha(w-116)\} - \lambda_c \cdot c - \lambda_p \cdot p$.
	13. PROT-DEV [1/]	t	Developed Protection Level (threshold) $t = \text{Max}\{0, 1-(\lambda_c \cdot c+\lambda_p \cdot)\cdot\exp\{\alpha(116-w)\}\}$.
	14. PROT-FIXED	$u(w)$	Fixed Protection Level (See text) May replace PROT-DEV.
	15. PROT-MIN	$v(w)$	Min Protection Level (See text) A lower bound for PROT-DEV.

Figure 12

[1/] A special case of a quantity defined more generally. Cf. Figure 11.

[2/] Writing $f(w)$ as shown simply provides $0, 1, 2, \ldots$ as the range for $(116-w)$ while $w = 116, 115, 113, \ldots$. It would of course be equally correct to write $f(w) = \exp\{\alpha(w-116)\}$. Cf., however, the expression for "t" in 13.

$$P_o = q^{-k},$$

$$P_{i+1} = \{(k + i)(q - 1)/(i + 1)(q)\} P_i \ ; i = 0, 1, 2, \ldots \ .$$

The following is an equivalent form utilizing (m, q) wherein P_o is also displayed in form for actual computation.

$$P_o = \exp\{m(-\log q)/(q - 1)\},$$

$$P_{i+1} = [\{m + i(q - 1)\}/\{(i + 1) q\}] \cdot P_i \ ; i = 0, 1, 2, \ldots \ .$$

Current practice in the Optimum COSAL Program calls for q to be a function of m by table look-up. While actual values can be changed as parameters for calculation, the current table is as follows.

Mean m	Variance-to-mean ratio q
$0 < m \leq 0.75$	1.01
$0.75 < m \leq 1.20$	2.0
$1.20 < m \leq 2.00$	3.0
$2.00 < m \leq 3.00$	4.0
$3.00 < m \leq 5.00$	5.0
$5.00 < m \leq 7.00$	6.0
$7.00 < m \leq 8.00$	7.0
$8.00 < m$	8.0

It can be shown that the above approximates the Poisson probability distribution for $m \leq 0.75$ since this latter is a limiting case of the negative binomial for q approaching unity in the limit.

2) Scaling parameters have been used as follows in order to obtain actual scaling functions for use in Optimum COSAL calculations.

	Scaling Parameter	Scaling Function Value
MEC	$\alpha > 0$	$f(w) = \exp\{-\alpha(116 - w)\}$
CUBE-RU	$\lambda_c \geqq 0$	$g(c) = \lambda_c \cdot c$
PRICE-RU	$\lambda_p \geqq 0$	$h(p) = \lambda_p \cdot p$

Recent calculations have been based on the following numerical values:

$$\alpha = 0.15 ,$$

$$\lambda_c = 3.163 \times 10^{-2} ,$$

$$\lambda_p = 1.0 \quad \times 10^{-5} .$$

Various matters concerning problems of scaling will be discussed elsewhere. However, the actual values listed above may be described as a set resulting from experimentation wherein the criterion employed for selection was that of producing certain desirable properties for the resulting allowance lists.

3) Cost data are computed as shown in Figure 12. These result from the choices for f, g and h listed just above plus

$$A = g(c) + h(p) ,$$

$$B = f(w) - A .$$

In words, the unit Holding Cost, A, is taken to be the sum of "scaled stowage space" and "scaled dollar value". Then the unit Shortage Cost, B, equals "scaled MEC" diminished by A. This latter may be expressed alternately by stating that the unit stockout penalty B equals $f(w)$ except that credit is taken for $g(c) + h(p)$; this latter sum is of course associated with stowage space and budget value not utilized on account of the item.

4) Protection levels of several kinds are utilized in current calculations. We again use t and C_n to denote respectively PROT-DEV and

PROT-ACH in the special cases for $\{P_i\}$, A and B as shown in Figure 12.

As presently used the Fixed Protection, PROT-FIXED denoted by $u(w)$, is employed solely for MEC 116 in which case it replaces PROT-DEV:

$$u(w) \text{ replaces } t \text{ for } w = 116 .$$

This means that the actual threshold t which is set for the cumulative probabilities C_s for the highest MEC class does not vary with price or cube.

A Minimum Protection, PROT-MIN denoted by $v(w)$ is currently used for $w = 115, 114, \ldots, 101$. In fact, whenever the PROT-FIXED is specified for a given MEC w then it is required that $v(w) = 0$, i.e., a PROT-MIN is not assigned. Current practice is as follows:

$$\mathrm{Max}[t, v(w)] \text{ replaces } t \text{ for } w = 115, 114, \ldots, 101 .$$

This use of $v(w)$ amounts to an "override" since it forces a lower bound for use as the threshold t against which the cumulative probabilities C_s are tested.

Exact conditions under which PROT-FIXED and PROT-MIN are applied are more in the province of [5] than of the present paper. For this reason, our present attention will be restricted to defining the range of possibilities for output data from Optimum COSAL calculations. This is done below for the "OVERRIDE" character written as a computational entry as shown in Figure 14. As will be seen below, one complicating factor in the "override" area is that for MEC 115, 114, ..., 101 current practice calls for an "MEC OVERRIDE" as follows:

$$\text{AQ-RU} = \mathrm{Max}[1, n] \text{ for MEC } 115, 114, \ldots, 101 .$$

There is some additional terminology. By the Group Protection for a particular MEC value w, we mean the product of the C_n for all allowance

list candidates having this particular MEC value. This means that the Group Protection is associated with a joint probability, i.e., the probability that demand will not exceed supply for any allowance list candidate in the given MEC class. The File Protection for MEC w represents the product of the Group Protections for MEC classes 116, 115, ..., w + 1, w. As such, it represents a joint probability for MEC class w and all higher classes. Finally, there is the concept of a Required Protection which is associated with the MEC override and which is defined below in connection with Field 53.

d) Computational entries.

Arithmetical operations are mainly performed on 20 position floating point words arranged according to the layout of Figure 13. Such a word is a 20 character alpha-numeric word composed of a 3 digit signed exponent juxtaposed to the left of a 17 digit signed mantissa. The exponent represents a power of 10 ranging from -999 to +999. A decimal point is understood to lie between digits 3 and 4, i.e., immediately to the left of the high order position of the mantissa so that the mantissa lies between -1 and +1. Each of the two positions of the word, the exponent and the mantissa is signed by its lowest order digit, Positions 3 and 20, respectively. Thus,

00A 33 ... 3C represents $(10)^{1}\cdot(+1/3) = +10/3$,

00A 33 ... 3L represents $(10)^{1}\,(-1/3) = -10/3$,

00J 33 ... 3L represents $(10)^{-1}(-1/3) = -1/30$,

00J 33 ... 3C represents $(10)^{+1}(+1/3) = +1/30$.

20 POSITION FLOATING POINT WORD

Contents	Exponent			17 Digit Mantissa							
Position	1	2	3	4	5	6	7	. . .	18	19	20

Signed Digit (position 3) — Signed Digit (position 20)

Exponent: Power of 10.
Signed by Digit 3.

Mantissa: Decimal Point understood to be immediately to left of Digit 4. Signed by Digit 20.

Positive	
Signed Digit	Printed Character
+ 0	$\overset{+}{0}$ 1/
+ 1	A
+ 2	B
+ 3	C
+ 4	D
+ 5	E
+ 6	F
+ 7	G
+ 8	H
+ 9	I

Negative	
Signed Digit	Printed Character
- 0	$\overset{-}{0}$ 2/
- 1	J
- 2	K
- 3	L
- 4	M
- 5	N
- 6	O
- 7	P
- 8	Q
- 9	R

Figure 13

1/ The character $\overset{+}{0}$ may appear in print as a plus sign (+), ampersand (&), or heavy bar (━).

2/ The character $\overset{-}{0}$ appears in print as light bar or minus sign (—).

The largest number which may be represented is $(10)^{999} \times (+0.99 \ldots 9)$ and the smallest (in an order sense) is $(10)^{999}(-0.99 \ldots 9)$. These two numbers possess the representations

99 I 99 ... 9I ,

99 I 99 ... 9R ,

respectively.

The smallest positive number which may be represented in this system is $(10)^{-999} \times (+0.00 \ldots 01)$ while the largest negative number which may be so represented is $(10)^{-999}(-0.00 \ldots 01)$. These numbers possess the representations

99 R 00 ... 0A ,

99 R 00 ... 0J ,

respectively.

Zero is represented by any one of the words

xyz 00 ... 0w

where x and y are each one of the characters 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, where z is a signed digit, and where w is one of the characters $\overset{+}{0}$ or $\overline{0}$.

Computational fields within the part records occupy Positions 200-385 as shown in Figure 14. Each of these fields will now be discussed in order.

Fields 48-52 are each 20 position fields in which floating point words are stored. Contents as shown correspond to status at the completion of an allowance list calculation. This accounts for the "initial" values for $i = 0$ in 48, 51 and 52 which are therein recorded for use in subsequent calculations.

Field 53 contains PROT-REQ, the Required Protection Level, which can most conveniently be defined in terms of the Override code from Field 62.

OPTIMUM COSAL REPAIR PART DATA MASTER RECORD
ALLOWANCE LIST CANDIDATES
COMPUTATIONAL FIELDS LAYOUT

Field No.	Notation for Field	Contents	Length of Field	Record Positions
48.		$P_i = P_o$	20	200-220
49.	FN-KAY	k	20	221-240
50.		$(q-1)/q$	20	241-260
51.		$i = 0$	20	261-280
52.		$P_i = P_o$	20	281-300
53.	PROT-REQ	"Required Protection". See text.	20	301-320
54.		Unassigned	4	321-324
55.	AQ-UA	Allowance Quantity in Units of Allowance	4	325-328
56.	AQ-RU	Allowance Quantity in Replacement Units	4	329-332
57.	POP-RU	Population in Replacement Units	6	333-338
58.		Unassigned	2	339-340
59.	PROT-ACH	Achieved Protection Level	20	341-360
60.	MEAN-<u>02</u>	Mean in RU per <u>02</u> months	10	361-370
61.		Unassigned	10	371-380
62.	OVERRIDE	See text.	1	381
63.	TRIP	"1" if record updated. See text.	1	382
64.		Unassigned	2	383-384
65.		End of record	1	385

<u>Notes</u> 1. Contents shown as of completion of Optimum COSAL calculation.

2. For part applications which are <u>not</u> allowance list candidates, the only computational field employed is Field 55 which may be filled by table look-up.

Figure 14

OVERRIDE CODE	REQUIRED PROTECTION
B, F, K or O	PROT-FIXED
A, E, J or N	PROT-MIN
C, G, L or P	B/(A + B)

Notice that if $B/(A + B) < 0$ then PROT-DEV is zero but Field 53 contains the negative quantity $B/(A + B)$.

Field 54 is unassigned.

Field 55 contains AQ-UA, the allowance quantity in units of allowance. For allowance list candidates, AQ-UA is the product of AQ-RU times RU and Field 56 is not blank. If it is non-zero it contains an integer quantity. In case the part is not an allowance list candidate, Field 56 is blank and Field 55 contains the result in 0.1 UA of the appropriate table look-up (e.g., ECN-APL) specified for the allowance list calculation, however, the decimal point is not written in Field 55. In all cases, the "allowance quantity" printed in the allowance list is the quantity expressed in whole units of UA.

Field 56, AQ-RU, duplicates Field 43.

Field 57, POP-RU, contains the installed population in units of the RU. It is to be noted that this is a six digit positive integer.

Field 58 is unassigned.

Field 59 contains PROT-ACH.

Field 60 contains m , e.g., MEAN-02, expressed to 4 D but the decimal point is not written in the record. The time period represented, e.g., 02 months, equals whatever time period had been specified for the Optimum COSAL calculation. In the absence of explicit documentation elsewhere, one could of course recover the time period in months from the record as (12 m)/(POP-RU)(UE-S).

Field 61 is unassigned.

Field 62, OVERRIDE, contains a one digit alpha-numeric code which indicates various facts concerning the processing of the allowance list candidate.

First, it indicates an <u>input control code</u> (F, W, M, 4, Blank, or +) which had been specified to define override rules for the item. Second, the OVERRIDE code indicates whether or not the PROT-ACH probability threshold was sufficient to produce a non-zero AQ-RU. For example, as shown below, Code K indicates a positive AQ-RU while the companion O indicates that one would have AQ-RU = 0 on the basis of the PROT-ACH calculation alone, i.e., without an MEC Override to set AQ-RU = Max[1, n].

Current practice calls for specifying an input code of F for MEC 116 and an M for every candidate in 115, 114, . . . , 101. The use of the M can provide the effect of guaranteeing not only a minimum PROT-ACH but also on the basis of MEC OVERRIDE it can provide for at least one RU being stocked for each allowance list candidate. This second feature can be adopted for such "high MEC" candidates for which

$$P_o \geq \mathrm{Max}[\text{PROT-MIN},\ \text{PROT-DEV}]$$

since for these the AQ-RU = 0 as explained above under b.7) in connection with the definition of PROT-DEV.

The actual table of codes is as follows.

INPUT CONTROL				OVERRIDE CODE Field 62 was [illegible] > 0?	
DOES PROT-FIXED APPLY?	DOES PROT-MIN APPLY?	DOES MEC OVERRIDE APPLY?	INPUT CODE	YES	NO
YES	NO	YES	F	K	O
YES	NO	NO	W	B	F
NO	YES	YES	M	J	N
NO	YES	NO	4	A	E
NO	NO	YES	Blank	L	P
NO	NO	NO	+	C	G

Field 63, TRIP, contains " 1 " in case the initial term for the negative binomial, P_o , has been computed and recorded in Fields 48 and 52. In case there is a " 1 " it means that the record has undergone an Optimum COSAL computation and the terminology "updated" is then used to describe the status of the record. Cf. [5].

Field 64 is unassigned.

Field 65 designates "End of Record".

5. Distributions for allowance list candidates.

The set of allowance list candidates for a vessel forms the domain for calculation of an allowance list model. This is true for the reason that these are the part applications for which it makes sense to try to optimize the on-board stocking quantity. In the first place, these parts constitute reasonable individual subjects because of their nature as members of a very large set of technical repair parts with uncertainly known future usages. For the FBM weapons system including not only the nuclear submarine but the missile system as well, there are more than 55,000 part applications: both the available stowage space and the budget make it impossible to stock "one or more of each" [1/] so that selection is required. The second fundamental attribute of

[1/] The following facts may be of interest. If one were to attempt to load "one each", i.e., a single RU for each allowance list candidate, the available stowage space of 2,500 cubic feet would be exceeded by more than 50%. In fact, the sum of CUBE-RU over all 55,918 allowance list candidates exceeds 3,800 cubic feet. The corresponding total for PRICE-RU is $3,500,000.00. Of further significance is the fact that the sum of CUBE-RU and PRICE-RU over the 31,200 distinct admissible Item Numbers equal nearly 3,300 cubic feet and $2,750,000.00, respectively. In other words, the entire range will not fit aboard the vessel and if one tried to load progressively starting with the highest MEC, the threshold of 2,500 cubic feet would be reached at the beginning of MEC 88.

an allowance list candidate is that adequate data exist so that an optimization model may be applied. Proceeding on to consider particular properties of the allowance list candidates, we find that we have to give attention to various combinations of elements of data as well as to the individual items of data defined above. Exactly this sort of scrutiny will be carried out in the present section wherein various tabular data will be displayed for the case of USS GEORGE WASHINGTON (SSB(N) 598). As another way of describing this section, it would be correct to state that it amounts to a summary numerical description of the USS GEORGE WASHINGTON from the point of view of the allowance list input data represented by [6].[1/]

a. Admissible parent SA's.

The highest level that we will examine is that of the Service Applications or SA's which consist of collections of CID's. For the input data represented by [6] there are 2187 distinct SA's. Of these, a total of 30 have no admissible CID's assigned, i.e., the only associated CID's are ECN-APL's. An additional 119 SA's are made up of admissible CID's which however have no installed allowance list candidates. There remain 2,038 SA's which are admissible parent SA's in that they involve allowance list candidates, i.e., each of these SA's has assigned to it at least one admissible parent CID. The make-up of these 2,038 SA's is given in Figure 15 which shows that roughly 75% have assigned to them only a single admissible parent CID.

[1/]The tabular data displayed below represent a small portion of that made available through several general tabulation programs prepared by Messrs. Edward Boback and Irwin L. Kwatek of the Project. It is furthermore appropriate to acknowledge the extensive use of these programs for checking various properties cited above for the files upon which the present paper is based.

DISTRIBUTION OF NUMBER OF CID's PER SA ADMISSIBLE PARENT SA's USS GEORGE WASHINGTON (SSB(N) 598)			
CID per SA	Number of SA's	Frequency of Occurrence	Cumulative Frequency
1	1,537	0.754	0.754
2	144	.071	.825
3	103	.051	.876
4	72	.035	.911
5	42	.021	.932
6	36	.018	.950
7-8	34	.017	.967
9-10	18	.009	.976
11-14	20	.010	.986
15-19	17	.008	.994
20-30	7	.003	.997
31-40	6	.003	1.000
41-237	2	.001	1.001
	2,038	1.001	

Figure 15

b. Admissible parent CID's.

Allowance List [6] was prepared from parts data corresponding to 3,541 different APL's. Of these 3,541 CID's, a total of 188 were ECN-APL's while 366 had no designated allowance list candidates. There remain 2,987 admissible parent CID's which were distributed over the 2,038 SA's of Figure 15 in the manner shown in Figure 16. According to Figure 16, 86.3% of these CID's were assigned to a single SA, 221 were assigned to two different SA's, etc.

The quantity 2,987 represents the range of the admissible parent CID's in that there are this many distinct entities. Their total depth is 17,808 (Cf. [3, Figure 29]) which is the total piece count in QC for the CID's. Figure 17 displays the distribution of QC for these CID's. While the number 17,808

DISTRIBUTION OF NUMBER OF SA's PER CID ADMISSIBLE PARENT CID's USS GEORGE WASHINGTON (SSB(N) 598)			
SA per CID	Number of CID's	Frequency of Occurrence	Cumulative Frequency
1	2,579	0.863	0.863
2	221	.074	.937
3	49	.016	.953
4	25	.008	.961
5	14	.005	.966
6	18	.006	.972
7	6	.002	.974
8	32	.011	.985
9-16	24	.008	.993
17-42	19	.006	.999
	2,987	0.999	

Figure 16

cannot be generated from Figure 17 due to the aggregation therein, it can be seen that the CID's with QC = 1, 2, 3, or 4 account for only (1)(1,571) + (2)(599) + (3)(141) + (4)(141) = 3,756 or roughly 21% of the total 17,808.

Figure 18 summarizes the distribution of MEC codes for the 2,987 CID's. (This particular table summarizes data presented earlier in [3, Figure 29]). A total of 5.9% are shown to have the highest rank, namely 116 which corresponds to a running mate [3] of 222 222.

As must be clear by this point, an actual allowance list determination is primarily based on calculations at the part level, i.e., for allowance list candidates. It is therefore appropriate to inquire into the make-up of the CID's under discussion in terms of numbers of installed wearable parts. This is done in Figure 19 which is the final summary for the CID's. The first column "SN per CID" actually denotes "the number of allowance list candidates

DISTRIBUTION OF QC ADMISSIBLE PARENT CID's USS GEORGE WASHINGTON (SSB(N) 598)			
QC	Number of CID's	Frequency of Occurrence	Cumulative Frequency
1	1,571	0.526	0.526
2	599	.200	.726
3	141	.047	.773
4	141	.047	.820
5-6	112	.038	.858
7-8	96	.032	.890
9-12	82	.028	.918
13-16	76	.025	.943
17-30	73	.024	.967
31-50	41	.014	.981
51-100	30	.010	.991
101-200	17	.006	.997
201-1,184	8	.003	1.000
	2,987	1.000	

Figure 17

corresponding to specific admissible CID's so that the entries made, e.g., for 6 denote a total of 163 CID's with 6 installed wearable parts in 5.5% of the total 2,987.

c. Allowance list candidates.

The 2,987 admissible parent CID's generate a total of 55,918 part-applications which are allowance list candidates. These latter are distributed

DISTRIBUTION OF MEC ADMISSIBLE PARENT CID's USS GEORGE WASHINGTON (SSB(N) 598)			
MEC	Number of CID's	Frequency of Occurrence	Cumulative Frequency
116	177	0.059	0.059
113-115	54	.018	.077
110-112	163	.055	.132
107-109	113	.038	.170
104-106	41	.014	.184
101-103	45	.015	.199
94-100	10	.003	.202
93	736	.246	.448
89-92	61	.020	.468
88	1,587	.531	.999
	2,987	0.999	

Figure 18

over CID's according to the tabulation of "SN per CID" shown above in Figure 19. They are distributed over MEC as shown in Figure 20. (These data and companion data showing "depth" as well, i.e., summations of POP-RU, were displayed in more detail earlier in [3, Figure 30].

A summary of the associated Usage Estimates-Ship or UE-S's is contained in Figure 21 while Figure 22 presents MEAN-02's which are the population weighted average usages for 02 months. Cube and price data are given in Figures 23 and 24, respectively.

Figures 25 and 26 describe the 55,918 allowance list candidates from the information contained in their individual stock numbers. It should be pointed out that the detailed data of Figure 26, the breakdown into Federal Supply Classes have to be interpreted within the context of this particular cataloging system. While this latter system will not be described here, it

DISTRIBUTION OF SN's PER CID ADMISSIBLE PARENT CID's USS GEORGE WASHINGTON (SSB(N) 598)			
SN per CID	Number of CID's	Frequency of Occurrence	Cumulative Frequency
1	550	0.184	0.184
2	325	.109	.293
3	234	.078	.371
4	213	.071	.442
5	213	.071	.513
6	163	.055	.568
7	111	.037	.605
8	100	.033	.638
9	70	.023	.661
10-11	153	.051	.712
12-13	115	.038	.750
14-15	80	.027	.777
16-17	56	.019	.796
18-19	55	.018	.814
20-25	107	.036	.850
26-50	201	.067	.917
51-100	130	.044	.961
101-200	82	.027	.988
201-300	15	.005	.993
301-1,128	14	.005	.998
	2,987	0.998	

Figure 19

DISTRIBUTION OF MEC ALLOWANCE LIST CANDIDATES USS GEORGE WASHINGTON (SSB(N) 598)			
MEC	Number of Part Appl.	Frequency of Occurrence	Cumulative Frequency
116	1,957	0.0350	0.0350
113-115	2,320	.0415	.0765
110-112	2,072	.0371	.1136
107-109	2,735	.0489	.1625
104-106	1,016	.0182	.1807
101-103	295	.0053	.1860
94-100	132	.0024	.1884
93	13,774	.2463	.4347
89-92	748	.0134	.4481
88	24,170	.4322	.8803
65-87	1,428	.0255	.9058
64	1,689	.0302	.9360
60-63	34	.0006	.9366
59	3,548	.0634	1.0000
	55,918	1.0000	

Figure 20

may be of help to observe that according to the "Federal Cataloging Handbook H 2-1", the FSC's are designed "to cover a relatively homogeneous area of commodities, in respect to their physical or performance characteristics, or in the respect that the items included therein are such as are usually requisitioned or issued together, or constitute a related grouping for supply management purposes".

d. Admissible Item Numbers.

The 55,918 allowance list candidates are made up of 31,200 distinct entities, i.e., admissible Item Numbers. Of these, as shown in Figure 27, roughly 75% have but a single application. These account for 23,407 allowance list candidates. The remaining (55,918) - (23,407) or 32,511

DISTRIBUTION OF UE - S ALLOWANCE LIST CANDIDATES USS GEORGE WASHINGTON (SSB(N) 598)				
Greater than	Less than or Equal to	Number of Part Appl.	Frequency of Occurrence	Cumulative Frequency
0.0000	.0001	3,236	0.0579	0.0579
.0001	.0100	6,164	.1102	.1681
.0100	.0200	4,570	.0817	.2498
.0200	.0300	6,333	.1133	.3631
.0300	.0500	10,857	.1942	.5573
.0500	.1000	10,090	.1804	.7377
.1000	.2000	3,657	.0654	.8031
.2000	.3000	3,315	.0593	.8624
.3000	.5000	5,440	.0973	.9597
.5000	1.0000	1,687	.0302	.9899
1.0000	160.0000	569	.0101	1.0000
		55,918	1.0000	

Figure 21

part-applications involve only 7,793 or (31,200) - (23,407) distinct IN's. These 7,793 IN's are distributed over from 2 to 138 different CID's in the manner displayed in Figure 27.

A final summary is included as Figure 28 in order to show the distribution of MAX MEC which is simply the maximum MEC for an IN over all CID's in which it is installed. Similar distributions of course exist for CUBE-RU, PRICE-RU, etc., for the 31,200 IN's but these will not be given in the present paper.

DISTRIBUTION OF MEAN - 02 ALLOWANCE LIST CANDIDATES USS GEORGE WASHINGTON (SSB(N) 598)				
Greater than	Less than or Equal to	Number of Part Appl.	Frequency of Occurrence	Cumulative Frequency
0.0000	0.0001	2,923	0.0523	0.0523
.0001	.0002	439	.0078	.0601
.0002	.0003	75	.0013	.0614
.0003	.0005	403	.0072	.0686
.0005	.0010	926	.0166	.0852
.0010	.0020	1,704	.0305	.1157
.0020	.0030	257	.0046	.1203
.0030	.0050	5,002	.0895	.2098
.0050	.0100	9,044	.1617	.3715
.0100	.0200	8,365	.1496	.5211
.0200	.0300	2,134	.0382	.5593
.0300	.0500	6,264	.1120	.6713
.0500	.1000	6,379	.1141	.7854
.1000	.2000	4,661	.0834	.8688
.2000	.3000	1,591	.0285	.8973
.3000	.5000	2,302	.0412	.9385
.5000	1.0000	1,642	.0294	.9679
1.0000	2.0000	947	.0169	.9848
2.0000	3.0000	279	.0050	.9898
3.0000	5.0000	232	.0041	.9939
5.0000	10.0000	184	.0033	.9972
10.0000	20.0000	88	.0016	.9988
20.0000	30.0000	26	.0005	.9993
30.0000	50.0000	23	.0004	.9997
50.0000		28	.0005	1.0002
		55,918	1.0002	

Figure 22

DISTRIBUTION OF CUBE - RU ALLOWANCE LIST CANDIDATES USS GEORGE WASHINGTON (SSB(N) 598)				
Greater than	Less than or Equal to	Number o Part Appl.	Frequency of Occurrence	Cumulative Frequency
.0000	.0001	2,902	0.0519	0.0519
.0001	.0002	5,821	.1041	.1560
.0002	.0003	2,170	.0388	.1948
.0003	.0005	1,864	.0333	.2281
.0005	.0010	8,043	.1438	.3719
.0010	.0020	6,983	.1249	.4968
.0020	.0030	4,252	.0760	.5728
.0030	.0050	4,492	.0803	.6531
.0050	.0100	6,914	.1236	.7767
.0100	.0200	4,027	.0720	.8487
.0200	.0300	1,593	.0285	.8772
.0300	.0500	1,597	.0286	.9058
.0500	.1000	1,722	.0308	.9366
.1000	.2000	1,384	.0248	.9614
.2000	.3000	684	.0122	.9736
.3000	.5000	476	.0085	.9821
.5000	1.0000	463	.0083	.9904
1.0000	2.0000	256	.0046	.9950
2.0000	3.0000	72	.0013	.9963
3.0000	5.0000	97	.0017	.9980
5.0000	10.0000	46	.0008	.9988
10.0000		60	.0011	.9999
		55,918	0.9999	

Figure 23

Note. The units of measurement are cubic feet.

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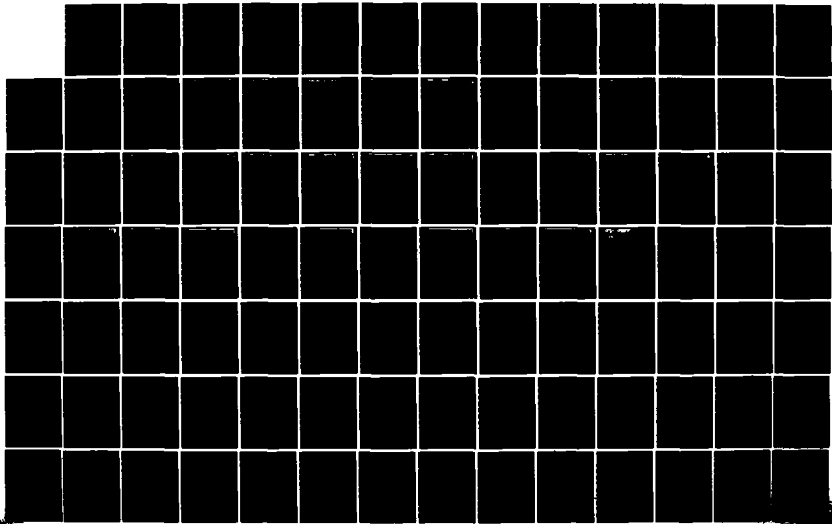

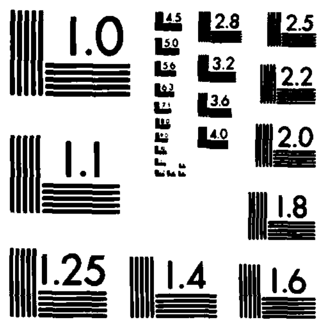

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DISTRIBUTION OF PRICE - RU ALLOWANCE LIST CANDIDATES USS GEORGE WASHINGTON (SSB(N) 598)				
Greater than	Less than or Equal to	Number of Part Appl.	Frequency of Occurrence	Cumulative Frequency
0.00	0.01	561	0.0100	0.0100
.01	.02	285	.0051	.0151
.02	.03	1,673	.0299	.0450
.03	.05	1,665	.0298	.0748
.05	.10	5,793	.1036	.1784
.10	.20	3,260	.0583	.2367
.20	.30	2,442	.0437	.2804
.30	.50	4,263	.0762	.3566
.50	1.00	6,656	.1190	.4756
1.00	2.00	6,176	.1104	.5860
2.00	3.00	3,215	.0575	.6435
3.00	5.00	3,681	.0658	.7093
5.00	10.00	4,300	.0769	.7862
10.00	20.00	3,451	.0617	.8479
20.00	30.00	1,601	.0286	.8765
30.00	50.00	1,811	.0324	.9089
50.00	100.00	1,613	.0288	.9377
100.00	200.00	1,157	.0207	.9584
200.00	300.00	612	.0109	.9693
300.00	500.00	684	.0122	.9815
500.00	1,000.00	533	.0095	.9910
1,000.00	2,000.00	200	.0036	.9946
2,000.00	3,000.00	96	.0017	.9963
3,000.00	5,000.00	82	.0015	.9978
5,000.00	10,000.00	68	.0012	.9990
10,000.00		40	.0007	.9997
		55,918	.9997	

Figure 24

MAJOR FEDERAL SUPPLY GROUPS ALLOWANCE LIST CANDIDATES USS GEORGE WASHINGTON (SSB(N) 598)		
Federal Supply Group	Number of Part Applications	
No Federal Stock Number	1,308	
10 Weapons	113	
12 Fire Control Equipment	575	1.0%
13 Ammunition and Explosives	29	
14 Guided Missiles	569	1.0%
16 Aircraft Components and Accessories	14	
20 Ship and Marine Equipment	170	
28 Engines, Turbines, and Components	572	1.0%
29 Engine accessories	164	
30 Mechanical Power Transmission Equipment	479	
31 Bearings	837	1.5%
34 Metalworking Machinery	35	
35 Service and Trade Equipment	41	
36 Special Industry Machinery	96	
40 Rope, Cable, Chain, and Fittings	20	
41 Refrigeration and Air Conditioning Equipment	209	
43 Pumps and Compressors	559	1.0%
44 Furnace, Steam Plant, . . . , Reactors	157	
45 Plumbing, Heating, and Sanitation Equipment	67	
47 Pipe, Tubing, Hose, and Fittings	396	
48 Valves	1,623	2.9%
49 Maintenance and Repair Shop Equipment	848	1.5%
51 Hand Tools	87	
52 Measuring Tools	19	
53 Hardware and Abrasives	7,514	13.4%
58 Communication Equipment	3,731	6.7%
59 Electrical and Electronic Equipment Components	31,244	55.9%
61 Electric Wire, and Power and Distribution Equipment	1,033	1.8%
62 Lighting Fixtures and Lamps	1,281	2.3%
63 Alarm and Signal Systems	74	
68 Instruments and Laboratory Equipment	1,798	3.2%
67 Photographic Equipment	104	
68 Chemicals and Chemical Products	13	
73 Food Preparation and Serving Equipment	18	
93 Nonmetallic Fabricated Materials	67	
Miscellaneous*	54	
Total: 100% =	55,918	93.2%

*A total of 18 additional groups appear each with not more than 10 part applications: 11, 15, 25, 39, 42, 46, 54, 55, 65, 69, 72, 74, 79, 80, 81, 91, 92, 95.

Figure 25

MAJOR FEDERAL SUPPLY CLASSES ALLOWANCE LIST CANDIDATES USS GEORGE WASHINGTON (SSB(N) 598)		
Federal Supply Class	Number of Part Applications	
No Federal Stock Number	1,308	
1220 F.C. Computing Sights and Devices	566	1.0%
1440 Launchers, Guided Missiles	314	0.6
3110 Bearings, Antifriction, Unmounted	619	1.1
4320 Power and Hand Pumps	309	0.6
4730 Fittings and Specialties: Hose, Pipe and Tube	361	0.6
4820 Valves, nonpowered	1,402	2.5
4935 Guided Missile ... Equipment	823	1.5
5305 Screws	672	1.2
5310 Nuts and Washers	896	1.6
5330 Packing and Gasket Materials	3,802	6.8
5340 Miscellaneous Hardware	1,338	2.4
5815 Teletype and Facsimile Equipment	2,991	5.3
5905 Resistors	11,481	20.5
5910 Capacitors	5,130	9.2
5920 Fuses and Lightning Arresters	982	1.8
5925 Circuit Breakers	448	0.8
5930 Switches	2,047	3.7
5935 Connectors, Electrical	2,960	5.3
5940 Lugs, Terminals, and Terminal Strips	704	1.3
5945 Relays, Contactors, and Solenoids	1,190	2.1
5950 Coils and Transformers	2,419	4.3
5960 Electron Tubes, Transistors, Rectifying Crystals	2,687	4.8
6110 Electrical Control Equipment	364	0.7
6210 Indoor and Outdoor Electric Lighting Fixtures	563	1.0
6240 Electric Lamps	455	0.8
6605 Navigational Instruments	670	1.2
6625 Electrical ... Electronic ... Instruments	431	0.8
6685 Pressure, Temperature, ... Instruments	344	0.6
Miscellaneous*	7,642	
Total: 100% =	55,918	84.1%

*A total of 166 additional classes appear, each with not more than 300 part applications.

Figure 26

DISTRIBUTION OF NUMBER OF APPLICATIONS ADMISSIBLE ITEM NUMBERS USS GEORGE WASHINGTON (SSB(N) 598)			
Number of Applications	Number of Item Nos.	Frequency of Occurrence	Cumulative Frequency
1	23,407	0.7502	0.7502
2	4,769	.1529	.9031
3	1,107	.0355	.9386
4	533	.0171	.9557
5-6	513	.0164	.9721
7-8	252	.0081	.9802
9-10	156	.0050	.9852
11-12	92	.0029	.9881
13-14	65	.0021	.9902
15-16	48	.0015	.9917
17-18	43	.0014	.9931
19-20	25	.0008	.9939
21-30	93	.0030	.9969
31-50	54	.0017	.9986
51-100	36	.0012	.9998
101-138	7	.0002	1.0000
	31,200	1.0000	

Figure 27

DISTRIBUTION OF MAX MEC ADMISSIBLE ITEM NUMBERS USS GEORGE WASHINGTON (SSB(N) 598)			
MAX MEC	Number of Item Nos.	Frequency of Occurrence	Cumulative Frequency
116	1,439	0.0461	0.0461
113-115	1,136	.0364	.0825
110-112	908	.0291	.1116
107-109	1,992	.0638	.1754
104-106	259	.0083	.1837
101-103	212	.0068	.1905
94-100	61	.0020	.1925
93	8,239	.2641	.4566
89-92	231	.0074	.4640
88	13,332	.4273	.8913
65-87	584	.0187	.9100
64	845	.0271	.9371
60-63	15	.0005	.9376
59	1,947	.0624	1.0000
	31,200	1.0000	

Figure 28

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POLARIS LOGISTICS STUDIES
Number 1

THE POLARIS MILITARY ESSENTIALITY SYSTEM

by

MARVIN DENICOFF
JOSEPH FENNELL
SHELDON E. HABER
W. H. MARLOW
FRANK W. SEGEL
HENRY SOLOMON

49p
h-2.00
mf-0.50

Serial T-171
24 July 1964

SUPERSEDES Serial T-148 (Revised)

THE GEORGE WASHINGTON UNIVERSITY
LOGISTICS RESEARCH PROJECT

Contract Nonr761
Task 03, Project NR 347 107
Task 05, Project NR 047 001
Task 06, Project NR 347 008

Office of Naval Research

THE GEORGE WASHINGTON UNIVERSITY
Logistics Research Project

Abstract
of
Serial T-171

SUPERSEDES Serial T-148 (Revised)

THE POLARIS MILITARY ESSENTIALITY SYSTEM

MARVIN DENICOFF
JOSEPH FENNELL
SHELDON E. HABER
W. H. MARLOW
FRANK W. SEGEL
HENRY SOLOMON

One of the major requirements for military systems has been the need for a measure of the relative importance of stocking one item rather than another. The present study develops one such system which has been implemented for the Polaris weapons system. Considerable emphasis is placed on systematic development of underlying principles. It is concluded that the present approach could readily be adapted to other weapons systems.

PREFACE

The present study is the first of several papers to be issued by this Project as Polaris Logistics Studies. Subsequent papers will consider allowance list determinations, FBM load lists for deployed tenders, ashore supply point problems, provisioning and procurement policies, and finally the general problem of providing logistics information and control systems to permit overall satisfactory logistics.

It will become apparent that the present series will represent a somewhat diverse range of interests. In addition to the fact that a somewhat heterogeneous set of research techniques will appear there is one feature which deserves special comment. This refers to the fact that careful attention is given to the underlying situations to which the methodology is to apply. It turns out that this introduces the need for considerable precision of terminology in engineering and logistics areas which unfortunately include areas notorious for their lack of standards, e.g., the problem of definition of a "component" as opposed to an "equipment". Nevertheless, a substantial part of the contribution of the present series is judged to consist of its relevance for practical problems; this has required that unswerving attention be paid to the exigencies of the background situations and their definitions.

It is a pleasure to acknowledge the support of the Logistics and Mathematical Statistics Branch of the Office of Naval Research under whose contracts this work has been performed. In just the same way, appreciation is due the Technical Director, Special Projects Office, and his Assistant for Material Support who are co-sponsors of this research by means of transfer of necessary funds to the Office of Naval Research. Mention should also be made of the fact that the Bureau of Supplies and Accounts and its field activities have been collaborators in the present studies. Finally, it is most appropriate to cite the essential assistance and support provided by the Logistics Research Project administrative and clerical staff and by the members of the Project Computation Laboratory who were essential for this work.

W. H. Marlow

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W. H. Marlow
Frank W. Segel
Henry Solomon

INTRODUCTION

The Polaris military essentiality system measures various effects of failures on the weapons system. Three different levels are considered: equipment, component and wearable installed part. A failure at one level is studied for its effect at higher levels; ultimately, the failed item is related to the Polaris mission. For example, the most important type of failure is one whose occurrence would force the submarine to terminate patrol and return to its base.

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[1] The preparation of this paper was sponsored by the Office of Naval Research and the Special Projects Office. Reproduction in whole or in part is permitted for any purpose of the United States Government.

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The above indicates our approach. We obtain relative measures of importance for all the items which go together to make up the Polaris weapons system. It turns out that if two items belong to the same military essentiality class (MEC), then by definition they are equally important. Otherwise, one of the items is more essential than the other for the weapons system capability. We develop 29 MEC's for component-equipment pairs; a repair part is classified as being one of 4 types so that parts fall into (4)(29) = 116 MEC's depending upon the MEC of their parent component-equipment.

In the present paper we are mainly concerned with shipboard repair parts inventory problems. Our actual vehicle for exposition is the allowance list problem which we will now define. An allowance list specifies the repair parts which must be carried on board ship. It is precise: all of the repair parts are identified and a quantity to be stocked is given for each part. Furthermore, only those parts are listed which are necessary for use by the ship's force for replacement in direct support of installed components. Without becoming overly technical, we may say that "direct support" means carrying out the ship's maintenance and repair policies so as to secure required military readiness.

We first describe the questionnaire approach which is basic to our work. This approach will be found to be similar to aspects of earlier studies by some of us on conventional submarines [1]. (See [2] and [3] for additional background.) Our major present contribution is judged to be the methodology leading to the final ranking system. Successively more extensive ranking schemes are developed until we reach the lowest level, that of repair parts. Throughout the development we aim at systematic procedures based on relatively few principles. At the end, we discuss practical applications.

QUESTIONNAIRE APPROACH

Three sets of questionnaires are used to determine effects of failures on the capability of the Polaris weapons system. There is a different questionnaire for use at each of the three levels: equipment, component and part.

How does one determine whether an item is an equipment, a component or a part? The answer is that it is a matter of definition by responsible technical authority. However, an equipment is generally directly related to some basic function in the weapons system. Very commonly there are components installed within an equipment and parts are installed in components. It can furthermore happen that a part is reparable. An example of an equipment is a "missile motion unit" in a fire control computer. Examples of components are: "alarm display panel", "ship velocity servo", and "power supply". Examples of parts are: "wire-wound 150 ohm resistor", "alarm switch plate", "6 volt indicator light", and "servo motor".

Basic Assumptions

We assume initially that the entire weapons system is composed of sub-systems which in turn are composed of equipments, components and parts as described above. Subsequently we will show how to treat exceptions such as an equipment with no component installed, a component without parent equipment, etc.

It will be convenient to employ the term application to denote a special type of functional assignment. By equipment application we mean a pair: a design entity called an equipment and a function performed. We require that each installed unit of an equipment be assigned to one and only one equipment application. In other words, more than one application for a given equipment means that several

units must be installed; if there are several units installed, there may or may not be more than one application. On the other hand, more than one equipment type may be assigned to a given application. Similar usage applies to the terms component application and part application.

Participating personnel were guided by the following assumptions in completing the military essentiality questionnaires.

1. The submarine is on a normal patrol cycle.

2. During the patrol cycle no supply or maintenance support is available from any external source.

3. A given failure could occur on the first day of patrol and the submarine would have to suffer the loss of the performed function for the entire patrol period.

4. The Polaris weapons system is composed of six independent sub-systems of equal military essentiality: launcher, fire control, navigation, missile, missile test and readiness, and ship.

The last sub-system, ship, consists of the nuclear submarine itself.

Equipment Questionnaire

The questionnaire shown in Figure 1 is to be completed for each equipment application.

In Section 1, Mission Effect, the participant considers the loss of the equipment application. He assumes simultaneous complete failure of all installed units of the given equipment assigned to this equipment application. There is no question of repair; instead he simply considers total loss. Perhaps there are additional equipments of different design assigned to this application so that loss of the given equipment may or may not lead to loss of the entire application. In

POLARIS MILITARY ESSENTIALITY SYSTEM EQUIPMENT QUESTIONNAIRE		
Equipment Identification Number ____ Application Identification Number ____ Number Installed ____		
Section 1	MISSION EFFECT (IF ALL FAIL)	Total Degradation . . . . x = 2 ☐ Partial Degradation . . . x = 1 ☐ Minimal Degradation . . . x = 0 ☐
Section 2	REDUNDANCY (IF ONE FAILS)	No Redundancy . . . . . y = 2 ☐ Reduced Effectiveness . . y = 1 ☐ Equivalent Effectiveness . y = 0 ☐
Section 3	ALTERNATIVES (IF ONE FAILS)	No Alternatives . . . . z = 2 ☐ Reduced Effectiveness . . z = 1 ☐ Equivalent Effectiveness . z = 0 ☐

Figure 1 - Equipment questionnaire

any event, the participant must select the appropriate box in Section 1. Choosing $x = 2$ for total degradation means that there would be complete loss of the sub-system so as to require termination of patrol: the ship would return to its base for repairs. Choosing $x = 1$ for partial degradation means reduced effectiveness of some significance but no termination of patrol. For example, depending on the type of failure there might be problems in selection of targets, speed of firing, defense capability, etc. The ship, however, would remain on patrol. Choosing $x = 0$ for minimal degradation means that there would be no effect on the mission capability for the length of the patrol.

In Section 2, Redundancy, the participant considers the loss of a single unit of the equipment. The response $y = 2$, "no redundancy", is correct for two situations. First, there may be only one unit installed in the given equipment application. Second, loss of a single unit may be the same as if all units had failed simultaneously. If neither of these two situations prevail, then the equipment application is not completely lost and one asks: what is the contribution of the surviving units? The choice $y = 1$ corresponds to multiple installations of identical equipments where the surviving units operate at some reduction in overall effectiveness. The choice $y = 0$ corresponds to no loss in overall effectiveness. It is to be stressed that Section 2 deals solely with effects of single equipment failures on immediate operation during a patrol: long range effects are to be disregarded. Finally, for use in what follows, we note that we are using the following definition of redundancy. Two or more equipments are redundant in case two conditions are satisfied. First, they are identical equipments assigned to a common sub-system equipment application. Second, loss of a single unit does not result in loss of the entire application.

In Section 3, Alternatives, the participant again considers the loss of a single unit of the equipment. But now he looks for substitute equipments which no longer must be identical but which must be assigned to different applications in the given sub-system. In particular, his first question concerns existence of an admissible alternative equipment. By definition, this is an equipment satisfying three conditions. First, it belongs to the same sub-system but it is assigned to a different application. Second, it could be substituted to permit continuous operation of the given equipment application in the event of failure of a single unit of the given equipment. Third, its primary application has $x = 0$. The response $z = 2$ is correct if there is no admissible alternative. Choosing $z = 1$ means that use of the most favorable existing admissible alternative would lead to reduced effectiveness in performance of the equipment application being rated. The choice $z = 0$ means that equivalent effectiveness would be possible.

Component Questionnaire

The questionnaire shown in Figure 2 is to be completed for each component application. By this we mean that one questionnaire is to be completed for each combination of component and parent equipment. There are three sections, each similar to the corresponding section in Figure 1. The major difference is that the questions here relate to effects on the parent equipment rather than on the mission of the weapons system.

In Section 1, Equipment Effect, the participant considers the loss of the component application. He assumes simultaneous complete failure of all installed units of the given component assigned to the given equipment. Choosing $u = 2$ means that there would be total

POLARIS MILITARY ESSENTIALITY SYSTEM

COMPONENT QUESTIONNAIRE

Component Identification Number ______________________

Application Identification Number ______________________

Number Installed ______________________

Section 1	EQUIPMENT EFFECT (IF ALL FAIL)	Total Degradation . . . . u = 2 ☐ Partial Degradation . . . u = 1 ☐ Minimal Degradation . . u = 0 ☐
Section 2	REDUNDANCY (IF ONE FAILS)	No Redundancy . . . . . v = 2 ☐ Reduced Effectiveness . . v = 1 ☐ Equivalent Effectiveness . v = 0 ☐
Section 3	ALTERNATIVES (IF ONE FAILS)	No Alternatives . . . . w = 2 ☐ Reduced Effectiveness . . w = 1 ☐ Equivalent Effectiveness . w = 0 ☐

Figure 2 - Component questionnaire

degradation of the given parent equipment. This would signify that the function of the given equipment would be completely lost to the subsystem. Choices $u = 1$ and $u = 0$ are counterparts to the earlier $x = 1$ and $x = 0$, respectively.

Section 2, Redundancy, where one of $v = 2, 1$ or 0 is to be chosen, is entirely analogous to the earlier case for y. Section 3, Alternatives, is slightly different in that an admissible alternative component is one whose primary application has either $u = 0$ or $x = 0$. For example, if there is no admissible alternative, then $w = 2$ is the correct response.

Parts Questionnaire

The questionnaire shown in Figure 3 is to be completed for each part application. That is, one questionnaire is to be completed for each combination of part and parent component. There are only two questions.

First, the respondent determines component dependence: can the parent component operate satisfactorily for the entire patrol period lacking one unit of the part? If the answer is "no", then the dependence is "major". On the other hand, the answer "yes" means "minor" component dependence on the part. Examples of this latter type of part are certain knobs, covers, washers, packing, etc.

The second question concerns installability: can the ship's force install the part during patrol? A "yes" answer means that replacement is permitted by established maintenance policy and it furthermore can be accomplished on patrol under normal operating conditions. A "no" answer could result from lack of required tools, inaccessibility, maintenance policy limitations, etc.

POLARIS MILITARY ESSENTIALITY SYSTEM

QUESTIONNAIRE

WEARABLE INSTALLED PARTS

Part Identification Number ____________________

Application Identification Number ____________________

Number Installed ____________________

		INSTALLABLE DURING PATROL ?	
		YES	NO
COMPONENT DEPENDENCE (IF ONE UNIT FAILS)	MAJOR	p = 1	p = 2
	MINOR	p = 3	p = 4

Figure 3 - Parts questionnaire

Based on the answers to the two questions, a value $p = 1, 2, 3$ or 4 results as shown in Figure 3. Our main attention will be directed at $p = 1$ and $p = 3$ which represent installable candidates for placement on the allowance list.

Questionnaire Data Coding

Filling out the MEC questionnaires produces sets of values for the variables shown in Figures 1, 2 and 3. The individual values will be called MEC digits: x, y, z and u, v, w range over 0, 1 and 2 while $p = 1, 2, 3$ or 4. Suppose now that a complete set of questionnaires has been filled out. To each equipment application there will correspond an equipment triplet $E = xyz$ which we write as a three digit number: e.g., $E = 222$, $E = 121$, etc. Similarly, to each component application there corresponds a component triplet $C = uvw$. It will also be convenient for us to denote the doublets yz and vw as redundancy-alternative doublets.

To each component application there corresponds a parent equipment application. Therefore, to each questionnaire producing a triplet C there is an associated equipment questionnaire assigning a triplet E. It will be convenient to consider the juxtaposition: to each component application there corresponds a CE - sextuplet $uvw\ xyz$. For reasons to be explained, we will always write the digits in this order (and not as $xyz\ uvw$) so we drop the prefix CE - and simply write sextuplet.

To each part application there corresponds a parent component-equipment with an associated sextuplet. This means that a total of seven digits are assigned to each part application, e.g., a pCE - septuplet. For brevity, septuplet will always be understood to mean this particular ordered arrangement: $p\ uvw\ xyz$.

DERIVATION OF MILITARY ESSENTIALITY CLASSES

We turn now to the problem of ranking the questionnaire data according to relative degrees of military worth. The most direct approach starts as follows. Among all equipments, $E = 222$ denotes the highest worth. This is true since the failure of such an equipment would totally degrade the mission capability of the weapons system and there is no redundant or alternative equipment available. On the other hand, $E = 000$ represents the least essential equipment: failure has a negligible effect, and furthermore, redundant and alternative equipments exist with comparable capability to the equipment itself. Similar analysis for component applications reveals the extreme cases $C = 222$ and $C = 000$. By pairing the highest worth component with the highest worth equipment we see that 222 222 is the highest possible ranking sextuplet. In other words, the component applications which are most essential for the mission are those which are most essential for the most essential equipments. In entirely analogous fashion, 000 000 is seen to be the lowest ranking sextuplet.

Among all part applications, those with $p = 1$ are clearly of highest essentiality. Those with $p = 3$ rank second for allowance list purposes. Non-installable parts with $p = 2$ or 4 are excluded from consideration. It is thus easy to find the two extreme cases for septuplets. The most essential part applications are those with $p = 1$ installed within component applications classified 222 222. In our standard notation, the septuplet 1 222 222 ranks highest. We similarly find that the combination of lowest part worth and lowest sextuplet forms the lowest worth septuplet. For allowance list candidates, this is 3 000 000.

As we have just shown, it is easy to find the extreme points for military essentiality. It is more difficult to rank intermediate degrees. There are 27 different E's, (27)(27) = 729 different sextuplets and 4(729) = 2,916 different septuplets. We will find that the 729 cases for component-equipment combinations are the hardest to handle. However, these 729 will be subdivided into 29 different classes through systematic argument based on relatively few principles. Once we have disposed of sextuplets, the problem of ranking septuplets yields immediately.

We will employ the familiar symbols for numerical inequalities: "$>$", "$<$", "$\geqq$", etc. It will also be convenient to interpret these symbols as comparisons of military essentiality for coded questionnaire data. For example, the symbol "$\geqq$" will denote "greater or equal military essentiality". Just as we have been doing in our verbal text, we will employ the terminology "higher rank" to mean "greater essentiality". Similarly, "more worth", "more essentiality" and "more important" mean the same. We offer a final caution in connection with the reversal of order between "higher essentiality" and "more satisfactory". The less satisfactory the situation in terms, for example, of mission effect or redundancy, then the higher the worth. Turning it around, the higher military essentialities correspond to the higher degrees of unsatisfactoriness with respect to the effects of failures on the entire weapons system.

The above notation and associated terminology are most natural. Not only is $0 < 1 < 2$ true for integers but it now becomes true in a military essentiality context as well: $0 < 1 < 2$ applies within each questionnaire section shown in Figures 1 and 2.

A most fundamental requirement which concerns consistency of ordering is transitivity. By definition this means that if $a > b$ and $b > c$, then $a > c$. Of course this holds for numbers; we require that it also be true for military essentiality. We will find this to be non-trivial in that certain ranking schemes must be rejected on account of their containing examples of intransitivity.

A second general requirement for an admissible military essentiality system deals with completeness. We will require that there be no unresolved orderings. Given two comparable elements, for example two triplets E_1 and E_2, we require the following: E_1 and E_2 represent equal essentiality or else one of them represents greater essentiality.

A third fundamental principle we apply concerns requirements for consistency in other things being equal situations. In general, suppose that two sets of questionnaire data agree in certain digit positions. Then an "other things being equal" requirement forces these data to be ranked according to their unequal digit positions. We will gain the effect of a two-digit requirement for equipment triplets. Then, for example, $211 < 221$ on the basis of the y's alone, but 212 and 221 cannot be related by this rule since they fail to agree in two positions. This last example has further interest. We will impose an x-digit "other things being equal" requirement so that 212 vs. 221 will be resolved in the same manner as the redundancy-alternative doublet situation 12 vs. 21.

Ranking Redundancy-Alternative Doublets

In order to rank the 27 different equipment triplets we first have to rank the 9 cases for redundancy-alternative doublets. We

choose equipment triplets $E = xyz$ for exposition but component triplets C would do as well. Furthermore, our arguments apply equally to doublets yz in triplets $2yz$, $1yz$ or $0yz$.

Let us first impose a one-digit "other things being equal" requirement: $y0 < y1 < y2$ and $0z < 1z < 2z$. Actually we have no choice since otherwise the ordering $0 < 1 < 2$ would not be preserved within z or within y. If we take this requirement together with transitivity we obtain some minimal conditions. These are shown by the following diagram.

$$\begin{tikzcd}
22 \arrow[r] \arrow[d] & 21 \arrow[r] \arrow[d] & 20 \arrow[d] \\
12 \arrow[r] \arrow[d] & 11 \arrow[r] \arrow[d] & 10 \arrow[d] \\
02 \arrow[r] & 01 \arrow[r] & 00
\end{tikzcd}$$

Here, one doublet represents higher worth than a second if it is possible to move from the first to the second via directed segments. Notice that this ordering is not complete since, for example, 12 vs. 21 is unresolved. However, whatever we do from this point onward in argument toward a complete ordering, we cannot violate any of the relations shown in the diagram. For instance, we must always have $21 > 10$.

Our second assumption is that "other things being equal", redundancy is preferable to alternatives in order to compensate for failures. Although there may be situations where this would be inappropriate, we take it as axiomatic that redundancy provides the better protection. Applying this principle we obtain the following relations: $02 < 20$, $01 < 10$ and $12 < 21$. This last case is

expressible in words as follows: redundancy alone with reduced effectiveness is more satisfactory than having only an alternative with reduced effectiveness.

As the third step we further strengthen our preference for redundancy over alternatives. We decide that having $y = 0$ is preferable to $y = 1$ or 2 whatever may be the value of z. An equivalent choice is to specify "$02 < 10$". Thus we determine at this stage three new orderings: $02 < 10$, $02 < 11$ and $02 < 21$.

The unresolved cases concern 11, 12 and 20. Of course $11 < 12$ so if there are no equalities, then there are three possibilities: $11 < 12 < 20$, $11 < 20 < 12$ or $20 < 11 < 12$. Our decision is to employ the first ordering; historically, this decision was endorsed by the USN Special Projects Office. In words, some redundancy with reduced effectiveness and no alternatives is preferable to having no redundancy but equivalent effectiveness via alternatives $12 < 20$. Our final result is the following ordering for redundancy-alternative doublets: $22 > 21 > 20 > 12 > 11 > 10 > 02 > 01 > 00$.

In summary, our development has established an ordering for doublets yz which agrees with their natural order as ternary or base-three numbers. This is displayed in Figure 4. Our conclusion is that one doublet has higher worth than a second if and only if its value as a ternary number is greater. Of course we are not saying that 20 is six times more important than 01. We assert only $20 > 01$ since $6 > 1$.

Ternary	Decimal
22	8
21	7
20	6
12	5
11	4
10	3
02	2
01	1
00	0

Figure 4 - Numerical representations of redundancy-alternative doublets

Ranking Equipment or Component Triplets

The central problem in the present section deals with 200 vs. 122 : does the "lowest" 2xy precede the "highest" 1xy ? If the answer is "yes", then reasonably 100 > 022 as well and all triplets are ordered, actually by ternary order. This indeed turns out to be the ordering chosen for triplets. Our development is phrased in terms of equipment triplets E = xyz but the arguments apply equally to component triplets C = uvw .

We observe that x is more significant for military essentiality than is either y or z. After all, x is derived from the assumption that "all units fail" and its exact effect on the mission capability. We decide that x has completely overriding importance: in particular, 200 > 122 and 100 > 022 . As a matter of

orical interest, the Special Projects Office endorsed this decision: ission effect $x = 2$, even when it can be completely compensated for by redundancy and when at the same time equivalently effective rnatives exist (200) is more unsatisfactory than a mission effect ' modified by no redundancy and no alternatives (122). As mentioned in the preceding paragraph, this is the first path to ternary order hown in Figure 5.

ernary	Decimal	Ternary	Decimal	Ternary	Decimal
222	26	122	17	022	8
221	25	121	16	021	7
220	24	120	15	020	6
212	23	112	14	012	5
211	22	111	13	011	4
210	21	110	12	010	3
202	20	102	11	002	2
201	19	101	10	001	1
200	18	100	9	000	0

Figure 5 - Numerical representations of equipment or component triplets

There is a second rationale whereby one can derive ranking emes for triplets, namely the <u>dominant relation approach</u>. The idea derive triplet order from doublet order. Given two triplets, we struct doublets and then make pairwise comparisons by the ranking

system for doublets. The ordering for the two triplets then equals the dominant, e.g., most prevalent, doublet relation: >, < or = . Very often the dominant relation is simply determined by majority rule. however, there may have to be "tie breaker" rules to handle certain otherwise unresolved cases.

In the present context a reasonable dominant relation scheme is the following. Given $x_1 y_1 z_1$ vs. $x_2 y_2 z_2$ we consider three doublet comparisons: $x_1 y_1$ vs. $x_2 y_2$, $x_1 z_1$ vs. $x_2 z_2$, and $y_1 z_1$ vs. $y_2 z_2$. If each doublet comparison is made according to ternary order then we are recognizing decreasing significance from x to y to z. This is true since x appears as the more significant digit twice, y appears once and z not at all. We note further that these joint considerations seem naturally inspired: xy and xz combine results of failures with possible compensations while yz deals solely with means for compensation. It turns out that always one of ">" or "<" dominates, i.e., there are no ties, and ternary order for triplets again results, this time from using a dominant relation approach.

It would be possible to use any acceptable ordering for doublets with the scheme of the preceding paragraph. There might have to be additional rules in order to obtain a complete ordering for triplets: obtaining >, =, < in some order or one of >, =, = or <, =, = could be considered to be a "tie". Recall that there were two unexplored possibilities for doublet ordering: $12 > 20 > 11$ and $12 > 11 > 20$. If we use the first and complete the ordering for doublets we obtain $22 > 21 > 12 > 20 > 11 > 10 > 02 > 01 > 00$. But this doublet ordering yields an <u>intransitive triplet</u> ordering: $202 > 112 > 220$ from which $202 > 220$ by transitivity yet direct

calculation also produces 220 > 202 . On the other hand, 12 > 11 > 20 produces the following perfectly well behaved triplet ordering.

222 > 221 > 212 > 211 > 122 > 121 > 112 > 111 > 220 >
210 > 120 > 110 > 202 > 201 > 102 > 101 > 200 > 100 >
022 > 021 > 012 > 011 > 020 > 010 > 002 > 001 > 000

The triplets in the first line with $x = 1$ are increased in worth over that in the ternary system of Figure 5 while those in the second line with $x = 2$ have of course been downgraded. Other changes may be noted as well.

We conclude our treatment for triplets by agreeing upon ternary order. This means that we accept the relative order 0, 1, 2, ..., 26 as shown in Figure 5. Once again we stress that 110 > 002 since 12 > 2 but 110 does not necessarily represent six times more essentiality than 002.

Ranking Component-Equipment Sextuplets

Two components installed in the same equipment can be ranked by the triplet ordering system of the preceding section. This is a matter of "other things being equal". However, two different component applications will in general have different equipment triplets. For this reason we need an ordering system for sextuplets to rank all component applications. Looking ahead, the higher ranked component application will be the one which will be given more repair parts support.

We attach more significance to C than to E; this is reflected in our writing the component digits to the left: uvw xyz.

The basic reason is that we would rather stock repair parts for an absolutely critical component in a zero-worth equipment than for a 000 component in a 222 equipment: in symbols, 222 000 > 000 222. Repair parts are installed in components so that for allowance list purposes components are somewhat more basic than equipments. A second reason for attaching more significance to C than to E is that often an equipment has less tangible meaning than does a component. At times, for example, an equipment is merely a cabinet in which components are installed.

A simple example will show why we reject ternary order for sextuplets: 221 222 vs. 222 000. The respective decimal equivalents are 701 and 702 yet we believe that 221 222 > 222 000. Our reasons are straightforward. The first sextuplet, 221 222 represents a highly unsatisfactory situation: the component is the second most critical type and it is installed in the most critical type equipment. On the other hand, 222 000 represents a critical component installed in the very lowest worth equipment. Loss of the function of this equipment would cause minimal degradation of the mission; moreover, the equipment can be compensated for either by redundancy or by alternatives with either providing equivalent effectiveness. In conclusion, we note that rejection of ternary order is not a consequence of our writing C E rather than E C. This fact can be seen by verifying that if we interchange and write E C, then the situations are different but again 221 222 > 222 000.

There is a straightforward method for ranking the 729 sextuplets which avoids the pitfalls of intransitivity and incompleteness of order. The method consists of making up a precedence list which directly assigns the sextuplets into rank 1, 2, ..., 729. No formal "system" is required. But this approach suffers from the fact

that 729 sextuplets are too many for convenient manual juggling. This inconvenience is particularly significant if one insists, as we do, that the ordering satisfy minimal "other things being equal" properties: for example, $C_1 E_1 > C_1 E_2$ if and only if $E_1 > E_2$ and $C_1 E_1 > C_2 E_1$ if and only if $C_1 > C_2$.

The alternative to initial ordering by means of a sextuplet precedence list is use of a binary rule which applies to pairs of sextuplets. Such a rule establishes a procedure for determining which of two sextuplets has the higher worth. Given such a rule, we can use the following procedure to try to develop a precedence list for verifying transitivity and completeness of order. We first compare each pair of sextuplets. Then, for each sextuplet s, we count the number of sextuplets which do not have worth higher than s and call this number the tally $t(s)$. Suppose next that the values of $t(s)$ are tabulated for all s. The first case to be distinguished is Case 1: there are no duplicate values of $t(s)$. Here there are no difficulties and the sextuplets are consistently ordered by their tallies: $s > s'$ if and only if $t(s) > t(s')$. We also note that in Case 1 no two sextuplets are assigned equal worth. Case 2 occurs when there are duplicate values of $t(s)$. Then certain sextuplets are assigned equal worth and there are two possibilities: 2a or 2b. In Case 2a $s > s'$ occurs if and only if $t(s) > t(s')$. This means the sextuplet ordering based on the binary rule agrees with the precedence list based on tallies. This common ordering is furthermore transitive and of course there are no unresolved orderings. Case 2b occurs when there exists a pair of sextuplets s and s' such that $s > s'$ by the binary rule but $t(s) < t(s')$. In this case we reject the original binary rule as unsatisfactory since, as we will now show, Case 2b has the fatal defect of intransitivity. Since $s > s'$, all sextuplets ranking

below s' would also rank below s by transitivity. But this contradicts $t(s) < t(s')$ which states that there are more sextuplets which do not rank higher than s' than those for s. In summary, given a binary rule for ranking sextuplets, we would test it as follows. First, it must lead to Case 1 or Case 2a. Second, it must satisfy the "other things being equal" properties listed at the end of the preceding paragraph. Third, it must rank "correctly" those cases which can be resolved by other methods, e.g., 221 222 > 222 000 as we decided in rejecting ternary order. The rule would also have to attach more significance to C than to E and this in turn would lead to other "test cases".

Our attempts at binary rules for sextuplets based on the dominant relation approach were generally unsuccessful. These rules would commonly fail one or more of the tests mentioned just above. Nevertheless, it seems worthwhile to give one example to illustrate the approach. We could use digits, doublets, or triplets alone or in combination since we have ranking systems for each. However, for a typical illustration we simply extend jointly to C and E the method of comparing three sets of doublets per triplet: uv, uw, vw; xy, xz and yz. Then the dominating relation in the sense of majority rule over the six doublet comparisons will be designated as the relation holding between the sextuplets. In case of no majority then the sextuplet with the higher ranking C will be the higher ranked. For example, in this way, 200 000 > 000 020. This same pair also illustrates failure of transitivity: 000 020 > 000 011 > 200 000 by two comparisons. But this implies 000 020 > 200 000, a contradiction. We therefore reject this particular example of a binary rule for ordering sextuplets.

Our chosen approach uses <u>numerical valued functions</u> defined on the sextuplets. Two sextuplets are then related in the same order as their respective functional values. Instead of considering functions of six variables, u, v, w, x, y and z, it will be sufficient for our purposes to consider the two variables C and E. Actually, it will be more convenient to use their <u>decimal representatives</u> which will be denoted by (*).

$$C^* = 9u + 3v + w$$
$$E^* = 9x + 3y + z$$

Then if Z is a numerical function on the C^*E^* - plane,

$$C_1E_1 \leqq C_2E_2 \quad \text{if and only if} \quad Z(C_1^*, E_1^*) \leqq Z(C_2^*, E_2^*)$$

Attention will now be transferred to possibilities for Z which will yield acceptable orderings.

Our "other things being equal" requirements translate as follows:

$$\text{If} \quad C_1^* \leqq C^*, \quad \text{then} \quad Z(C_1^*, E^*) \leqq Z(C^*, E^*)$$

$$\text{If} \quad E_1^* \leqq E^*, \quad \text{then} \quad Z(C^*, E_1^*) \leqq Z(C^*, E^*)$$

These two properties plus transitivity divide the C^*E^* - plane into four rectangles as shown in Figure 6. All points within the two shaded portions can be ranked as shown relative to (C_1^*, E_1^*). We have drawn a line

$$C^* + E^* = \text{constant}$$

which could conceivably represent a symmetric separation of the plane: all points to the right of this line could be ranked higher than (C_1^*, E_1^*) while points to the left would represent lower military

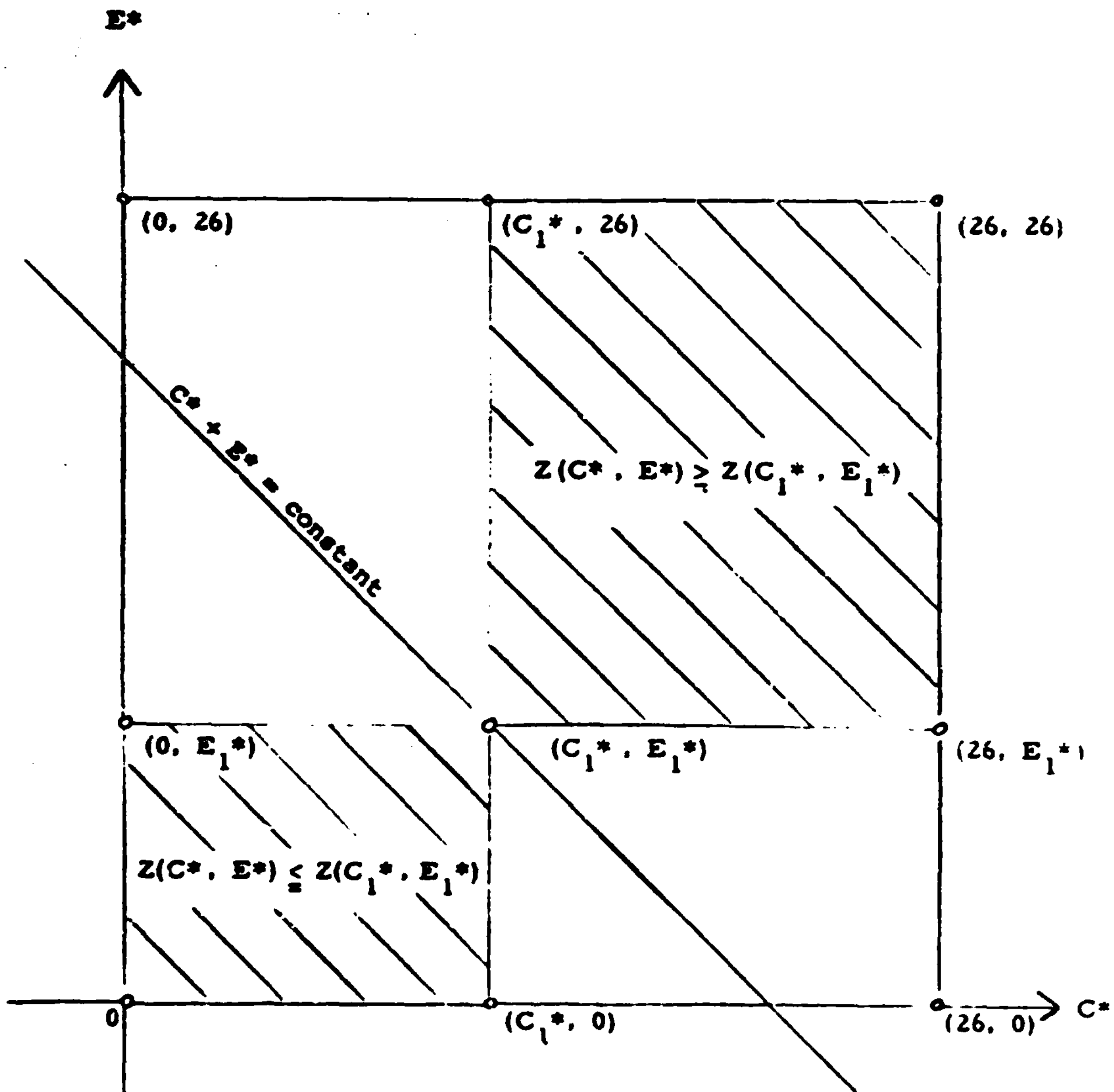

Figure 6 - The component-equipment plane

ssentiality. It will turn out that we will use this type of separation for ur final sextuplet ranking system. In general, we wish to separate the lane by means of a line $aC_1^* + bE_1^* = \text{constant}$. The slope of iis line must be -1 or less in order that not less significance be ttached to C than to E. For this last equation then, $a \geqq b > 0$ o that in terms of the slope, $-(a/b) \leqq -1$.

Granting that the $C^* E^*$ - plane should be separated by a line s discussed above, what should be done on the line itself and how hould different lines compare? It turns out that there are only three cceptable possibilities as exemplified by Figure 7 where, for simlicity, we consider a slope of -1.

Option I corresponds to attaching overwhelming significance to rather than to E. On a given line the points are ranked so that ney strictly decrease with decreasing C^*. With regard to two dif- erent lines, "other things being equal" imposes obvious restrictions n relative order for points with common coordinates. There are, owever, two different possibilities under Option I. First, the lines nay be strictly ranked by C^* so that the minimum rank point on one ne exceeds the maximum on the next "lower" line. Second, the bove order may not hold in that some points on a "higher" line may orrespond to "lower" functional values.

Option II is clearly represented in Figure 7. As is there shown, very point on one line can rank higher than every point on the imme- iately following line. There is a second possibility under Option II: ll elements on two adjacent lines could represent identical worth.

Option III ranks intermediate points highest as would be consist- nt with the following point of view. Having both C^* and E^* omewhat low but neither extremely low nor extremely high represents

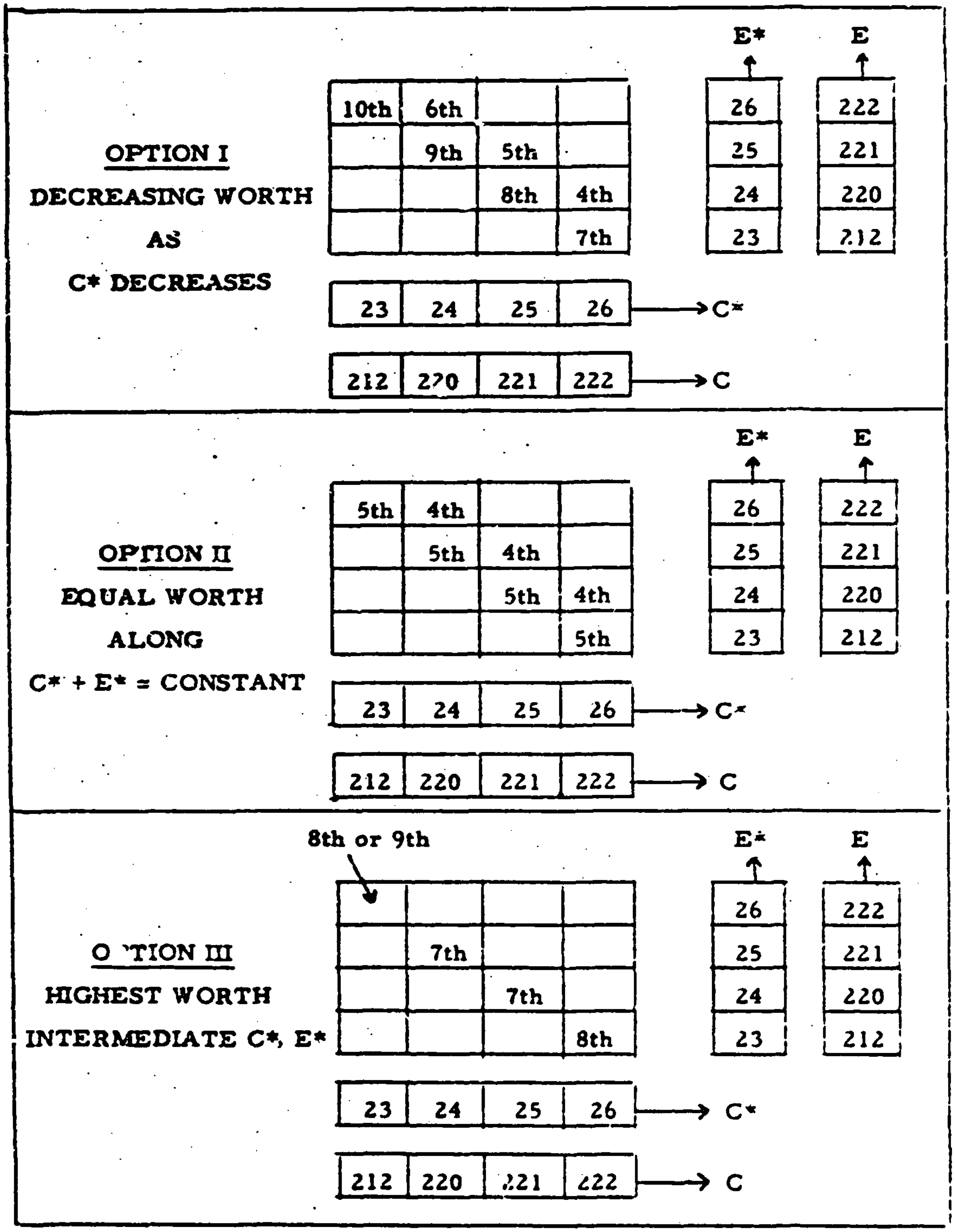

Figure 7 - Possibilities for relative essentiality along the lines C* + E* = constant

a worse situation than a higher C^* coupled with a lower E^*. Finally, this latter combination might be judged to be not better than a low C^* coupled with a high E^*. These are in fact our reasons for permitting Option III.

Options I, II and III represent all acceptable possibilities. Our requirement for attaching more significance to C than to E would rule out increasing worth for decreasing C^*. It would also rule out reversal of relative order for end points in Option III. Finally, a true minimum will not be allowed at an intermediate point for the very reasons which led us to permit Option III. Any true minima must be assumed at a set of points which may include only one end point in which case it is the left (Options I or III) or else this set includes both end points (Option III). Any true maxima must occur on a set including at most one end point in which case it is the right (Option I) or else it occurs only at interior points (Option III). We will find it appropriate to invoke each of Options I, II and III at some stage of our subsequent derivation of a final ranking system for sextuplets.

Before completing our chosen system for ordering sextuplets let us exhibit a few examples. Acceptable numerical functions are quite easy to find since we are limiting our attention to ordinal properties. That is, our ultimate objective is a precedence list for sextuplets, we are not attempting to assign absolute numerical measures of military essentiality. It turns out that linear functions are often sufficient. In the present Polaris context we are led to

$$Z(C^*, E^*) = aC^* + bE^*$$

where $a \geqq b > 0$ by virtue of the argument given above in connection with Figure 6. Actual values for a and b are determined by

fixing the relative magnitudes of $Z(26, 0) = 26a$ and $Z(0, 26) = 26b$. For example, $Z = C^* + E^*$ ranks sextuplets according to Option II. Option I is illustrated by $Z = 2C^* + E^*$ and $Z = 27C^* + 26E^*$. This latter example has the feature that no two sextuplets are given equal rank; furthermore, lines $C^* + E^* =$ constant are strictly ranked. Option III is illustrated by the non-linear $Z = C^*E^* + C^*$ whose values tend to peak at intermediate points (C^*, E^*) on any line $C^* + E^* =$ constant. The interested reader may readily verify that the examples of the present paragraph lead to interesting sextuplet precedence lists.

It will now be easy to explain the sextuplet ranking scheme chosen for the Polaris military essentiality system. We recall that the "equipment effect" digit u and the "mission effect" digit x were judged to be the most significant digits in the triplets C and E, respectively. This decision was made on the basis of their defining properties: for each of u and x we had assumed that "all units failed" and then we determined the exact consequences. In order to rank sextuplets we now start with joint consideration of u and x as shown in Figure 8. By virtue of their meaning as questionnaire responses, we define a sextuplet to be "high worth" in case it falls into one of Blocks 22, 21 or 12 as shown in Figure 8. This of course means that in such a sextuplet at least one of u and x is "2" and neither equals "0". Turning around this same argument, Blocks 00, 10 and 01 represent "low worth" since here at least one of u and x is "0" and neither equals "2". There remain Blocks 11, 20 and 02 which represent "intermediate worth". We shall consider the major subdivisions separately, starting with the "high worth" category.

The six highest of the "high worth" sextuplets will be ranked by Option I. Certainly 222 222 ranks highest while 222 221 and

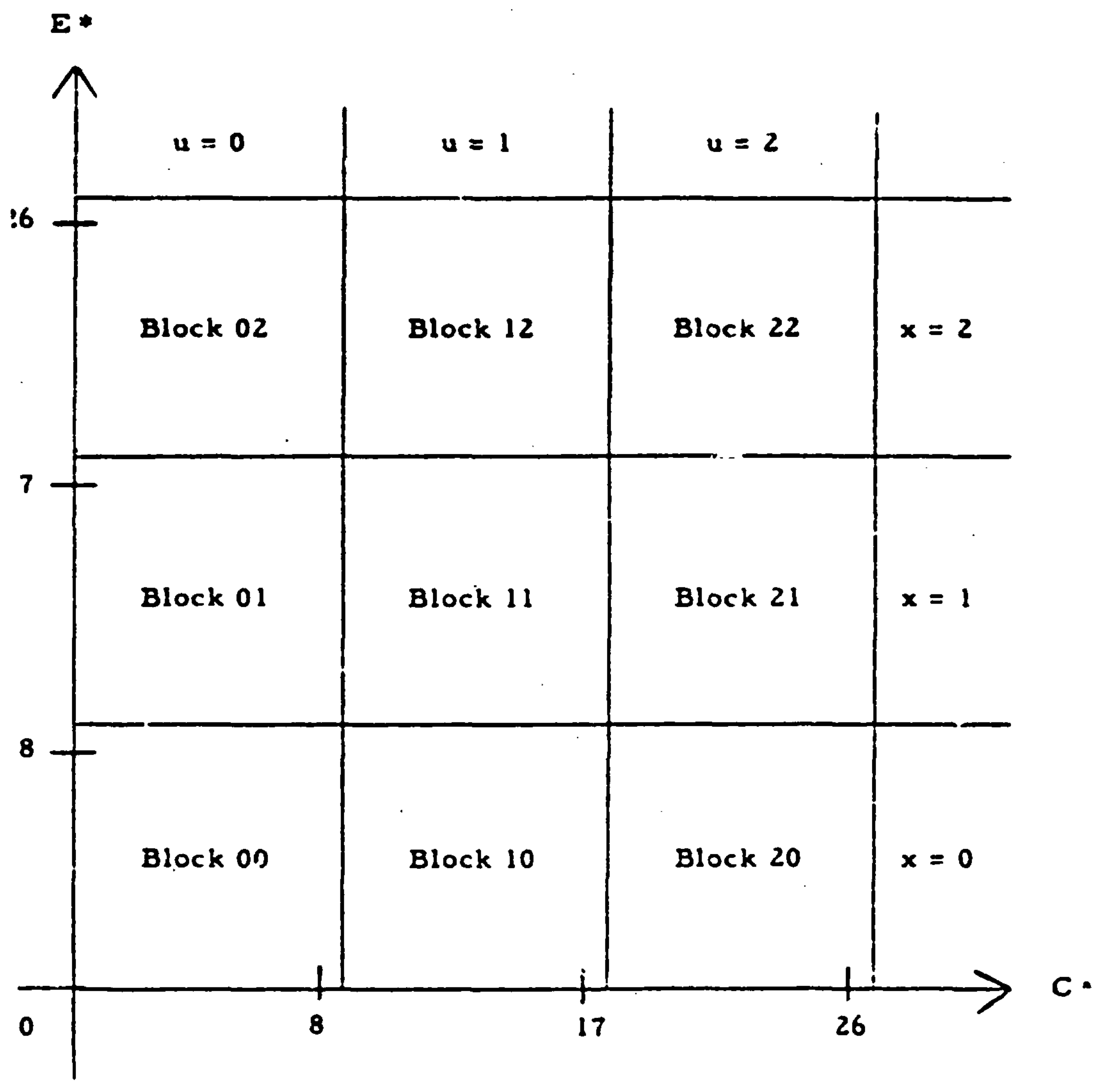

Figure 8 - Partition of C* E* - plane into ux - blocks

221 222 contend for second and third rank. According to Option I, which we recall is based mainly on attaching more significance to C than to E, we rank the first six sextuplets as follows.

1st:	222 222
2nd:	222 221
3rd:	221 222
4th:	222 220
5th:	221 221
6th:	220 222

Notice that 4th, 5th and 6th ranks are assigned exactly as shown for Option I in the uppermost panel of Figure 7. Notice also that these three sextuplets lie on the line $C^* + E^* = k$ for $k = 50$. We continue with Option I line by line for $k = 49, 48, \ldots, 35$ so that each point on any given one of these lines follows all points on lines with higher k's and precedes all points on lines with lower k's. However, we apply Option II within each line so that two points lying on the same line are given equal rank. Combining all points on a single line into a single MEC is consistent first of all with the less and less sharp distinctions between different points on a single line as k decreases. Secondly, such lumping together reduces the number of MEC's and so affords simplicity. We stop at $k = 35$ to avoid running into Block 11. All points on $C^* + E^* = 35$ from 222 100 to 100 222 are ranked 21st. With this assignment, ranking is complete for the entire Block 22 and for one-half of each of Blocks 21 and 12. To finish ranking all high worth sextuplets we assign rank 22nd to the lower triangular half of Block 21 and 23rd rank to each point on the lower triangular half of Block 12. This choice is another instance of Option I. A pictorial representation of the final ordering is given in Figure 11 below, where, for reasons to appear, the quantity "117-rank"

is entered as a code: 1st rank becomes code 116, 21st becomes 96, 23rd becomes 94, etc.

The "intermediate worth" Blocks 11, 20 and 02 will be ranked by Option III applied to entire blocks. Our reasons coincide with those advanced above in our hypothetical discussion of Option III. All sextuplets in Block 11 are assigned 24th rank, Block 20 becomes 25th rank and Block 02 becomes 26th rank. We consistently rank Block 20 higher than 02 but, by Option III, we give Block 11 first rank. In Figure 11 below, the present blocks are coded 93, 92 and 91.

Among the "low worth" blocks, Block 00 ranks lowest, Block 01 ranks second lowest and Block 10 ranks highest. This is Option I. In Figure 11 below, Blocks 10, 01 and 00 are coded 90, 89 and 88, respectively.

In conclusion, the 729 sextuplets corresponding to questionnaire responses for component-equipment pairs have been subdivided into 29 classes as MEC's of relative worth. Two sextuplets belonging to the same MEC are regarded as representing equal military essentiality. In case we wished to rank the elements of one MEC we would apply the strict Option I within each MEC. In this way we could obtain up to 729 categories of sextuplet worth which would be consistent with our present ordering into 29 classes.

Ranking Part Application Septuplets

Two principles have been particularly fundamental for our development thus far. First, we agreed that redundancy is preferable to alternatives in order to compensate for failures. This led to our ordering system for triplets. Second, we attached more significance to C than to E and in this way arrived at our sextuplet ranking

system. We will now add a third principle: for allowance list purposes we attach more significance to the part worth digit p than to the sextuplet CE. In fact, the nature of the part application -- installable or not and critical or not -- will be given overriding significance.

We recall from Figure 3 that if $p = 2$ or 4 the part cannot be installed by ship's force. Such a part is excluded from shipboard stocking. Thus, other things being equal, part worth digits are ranked for allowance lists in order $1 > 3 > 2 > 4$. As we have noted, a part application with $p = 1$ will be ranked higher than any other with $p = 3$ whatever may be the nature of the parent component-equipments. We would rather stock a critical $(p = 1)$ part for a low worth parent $(000\ 000)$ than a non-critical $(p = 3)$ part for a high worth $(222\ 222)$ parent. In symbols for septuplets,

$$1\,C\,E > 3\,C\,E > 2\,C\,E > 4\,C\,E$$

so that in all there are $(4)(29) = 116$ MEC's for wearable installed parts. The top 29 classes, MEC codes 116, 115, ..., 88 for $p = 1$ are shown below in Figure 11. We display the full set of 116 codes in Figure 9. These codes serve as "ordinal locators" in the sense that one part application represents higher worth than another in case it has the higher MEC code.

PRACTICAL APPLICATION

At this point we have completed the development of an ideal Polaris MEC system. Our chief idealization has concerned formation of sextuplet data. In practice there exist exceptions to our rule that the entire weapons system consists of equipments constructed from components. We also anticipate that different persons may give different answers to the same questionnaire and that their responses must

SEXTUPLET CE		PART WORTH DIGIT			
C* + E*	Additional Requirements	p = 1	p = 3	p = 2	p = 4
52	222 222 only	116	87	58	29
51	222 221 only	115	86	57	28
51	221 222 only	114	85	56	27
50	222 220 only	113	84	55	26
50	221 221 only	112	83	54	25
50	220 222 only	111	82	53	24
49	None: 4 cases	110	81	52	23
48	None: 5 cases	109	80	51	22
47	None: 6 cases	108	79	50	21
46	None: 7 cases	107	78	49	20
45	None: 8 cases	106	77	48	19
44	None: 9 cases	105	76	47	18
43	None: 10 cases	104	75	46	17
42	None: 11 cases	103	74	45	16
41	None: 12 cases	102	73	44	15
40	None: 13 cases	101	72	43	14
39	None: 14 cases	100	71	42	13
38	None: 15 cases	99	70	41	12
37	None: 16 cases	98	69	40	11
36	None: 17 cases	97	68	39	10
35	None: 18 cases	96	67	38	9
< 35	u = 2 and x = 1, 36 cases	95	66	37	8
< 35	u = 1 and x = 2, 36 cases	94	65	36	7
< 35	u = 1 and x = 1, 81 cases	93	64	35	6
< 35	u = 2 and x = 0, 81 cases	92	63	34	5
< 35	u = 0 and x = 2, 81 cases	91	62	33	4
< 35	u = 1 and x = 0, 81 cases	90	61	32	3
< 35	u = 0 and x = 1, 81 cases	89	60	31	2
< 35	u = 0 and x = 0, 81 cases	88	59	30	1

Figure 9 - Definitions of MEC codes

be reconciled or consolidated. In the present section we consider these problems and others which may arise in practical application of our system.

Exceptional Cases for Questionnaire Data

The chief exceptions to our ideal hierarchy are components lacking parent equipments and equipments with no installed components. We solve these problems by assigning to each possibility a standard type septuplet called a running mate. That is, to each possible combination of questionnaire data describing a part application we assign a septuplet running mate. Our MEC codes 116, 115, ..., 1 apply to the running mate and then by association they apply to the original data.

Our system for assigning running mates is given in Figure 10 where "b" denotes no entry and " - " denotes any entry. The first entry, Special Projects, represents the standard data we have assumed to be available up to this time. This is the only case where the questionnaire data form their own running mate.

The second entry in Figure 10, Bureau of Ships, represents components lacking parent equipments. Historically, this has been the case for the components which make up the ship sub-system. The running mate is formed by copying the triplet C for use again as E. In the first place, this procedure corresponds to the fact that in the original data, "u" was actually determined as "x" : the first digit represented "mission effect" and not "equipment effect". No other procedure would make sense for this type of component questionnaire. Secondly, forming pCC means that a form of averaging is being used since the generated "E" stands between extremes 000 and 222 exactly as does the actual C .

QUESTIONNAIRE DATA	RUNNING MATE
Special Projects p uvw xyz	p uvw xyz
Bureau of Ships p uvw bbb	p uvw uvw
Exceptional Types	
1. p bbb xyz	p x22 xyz
2. p bbb bbb	p 222 222
3. b --- ---	4 000 000

Figure 10 - Septuplet running mate assignments

Running mates for Exceptional Type 1 questionnaire data are assigned from a more conservative point of view. That is, they are ranked somewhat higher than the corresponding "components only" cases described in the preceding paragraph. These latter data were formed by rating engineering entities which are well defined as possible consumers of repair parts. Type 1 data on the other hand are not so well defined: we therefore conservatively treat the equipment as a maximally critical component with x as given. We copy x for u and write 22 for vw. The reason we do not write u = 2 is that unless x = 2 there is no evidence to support the belief that loss of the function provided by the equipment would require terminating patrol.

Exceptional Types 2 and 3 are included in Figure 10 for completeness. In reality, they would mainly occur as errors in data.

Type 2 is a "non-installed" part to be treated as though it were of maximal importance. Type 3 goes to the lowest rank.

For $p = 1$ the procedures for assigning running mates produce assignments as shown in Figure 11. The initial entries "blank" are of course worthy of special notice: the first E row at the bottom of the figure displays the codes for "Bureau of Ships" data as defined by Figure 10; the first C column at the left represents "Exceptional Type 1" data.

Different Answers from Different Respondents

It is conceivable that different persons might make different Component or Equipment Questionnaire responses. In our experience such differences have been minimal over sets of similarly highly qualified people. Our original work was based on three sets of completed questionnaires, one each from manufacturer, Navy technical bureau and fleet. The answers were so consistent that we concluded that it would be advisable in the future to obtain single sets of answers. Nevertheless, different judgments will occur and it is important to be able to reconcile them.

The process of reconciling different answers is a problem that properly belongs to the responsible part of the organization which will use the MEC system. Our own approach which was accepted for the Polaris system was as follows. We proceeded digit by digit within Component and Equipment Questionnaires. If three answers were obtained and there was a majority, we adopted the common value, otherwise, we selected the average value "1". When only two answers were available, the larger digit was used for "u" or "x"; the smaller digit was used wherever there were two different answers for "redundancy" or "alternatives".

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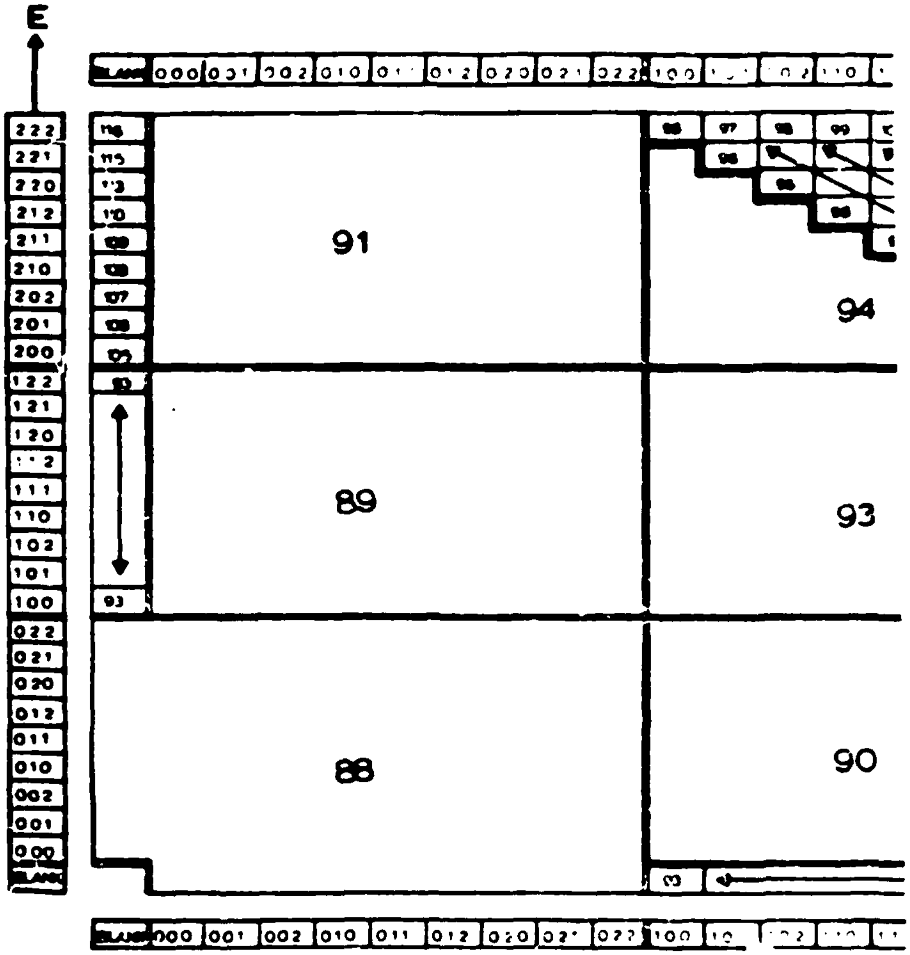
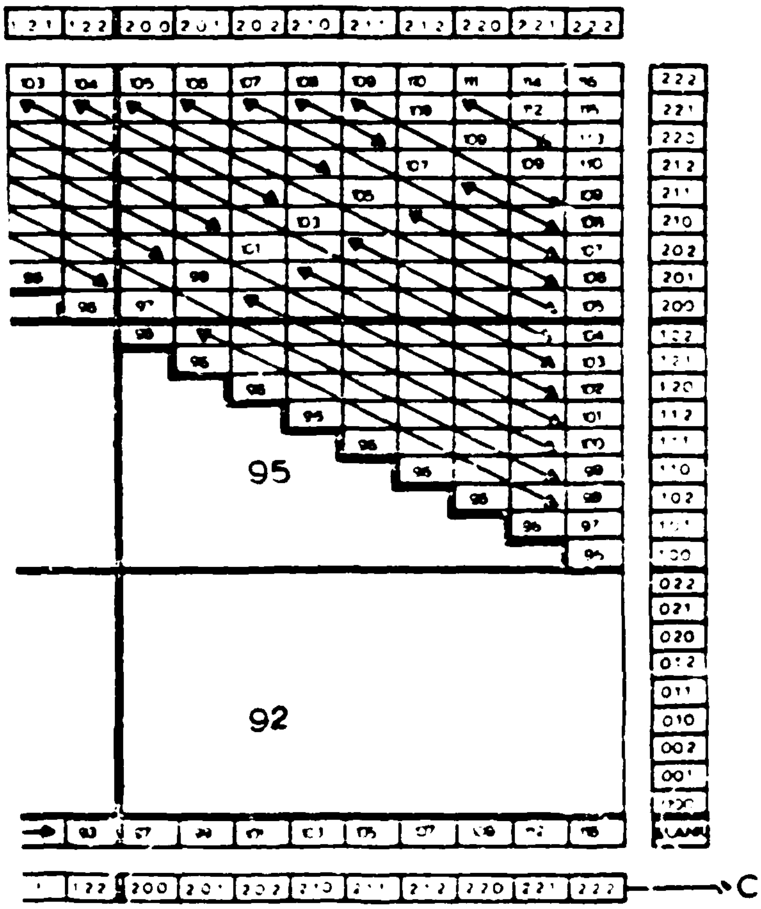


Figure 11 - Assignment of



des for p = 1

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Following any consolidation of multiple sets of questionnaire responses into a single set it is clearly advisable to have a review by competent authority. Such reviews have been most helpful in our experience both for direct product evaluation and for testing the rules for consolidation.

Different Answers for Different Applications

There will be a single triplet produced for each application of an equipment or component For each component in which a given part is installed there is required a separate part questionnaire. For some purposes there should be only a single triplet or a single septuplet associated with a single engineering entity. In other cases, multiple associations are suitable. Let us consider some possibilities for consolidation.

In the Navy the supply engineering documentation for a component or equipment does not vary by application. A single document is prepared to list the wearable installed parts and to furnish associated technical information. Thus, to compute an allowance list there may as well be a single determination covering all applications of a given component or equipment. This requires that we select a single MEC code. Our procedure is as follows. We obtain a single triplet by means of arithmetic averaging with normal rounding, digit by digit, for each of "effect", "redundancy" and "alternatives". The effect of normal round-off rather than "rounding up" is to avoid being overly conservative in borderline cases: for example, rounding up would cause each of the following to be judged as a "2" : 2, 1, 1, 1 or 2 with any number of 1's but no 0's . An additional reason for avoiding conservatism here is that the digit "p" is the dominant factor for

allowance list purposes anyway so that use of averages seems generally reasonable for component and equipment triplets.

If a repair part is installed in different parent components we generally retain separately its different MEC codes. Whenever it becomes advisable to consolidate, we recommend selecting the highest MEC code which ever appears for the given part. For example, our experience has shown that this procedure is preferable to using arithmetically weighted average MEC's based on frequencies of occurrence. The reason is simple. On board ship the repair parts are commonly kept in single bins and issued whenever needed. Thus, parts stocked for high worth applications can conceivably be consumed for low worth applications. We therefore recommend selecting the highest MEC code for a part whenever only a single code can be retained; in our experience this procedure does not lead to unwarranted over-stocking.

Results for Actual Data

The Polaris MEC system was developed in the manner described above in advance of any extensive application to non-hypothetical data. Subsequent experience with actual data has reinforced our convictions that the system is reasonable. For example, as shown for USS GEORGE WASHINGTON (SSB(N)598) in Figure 12, a good "spread" is obtained over the allowance list range. Similar distributions have been obtained for the other Polaris submarines; it is also interesting to compare [1] where only 15% of components and 28% of parts were "high worth". It has furthermore been true that MEC data have been easily obtained. Competent personnel at the manufacturing plants, at Navy technical bureaus or in the fleets can quickly and consistently fill out equipment and component questionnaires.

RELATIVE ESSENTIALITY	MEC CODES	COMPONENT-EQUIPMENTS	PART APPLICATIONS
Highest	116	6%	4%
High	115 . . 94	14%	15%
Intermediate	93 92 91	26%	25%
Low	90 89 88	54%	4[illegible]%
Lowest (p = 3)	87 . . 59	Does Not Apply	12%
	Total Range	2,987 component-equipments	55,918 part applications

Figure 12 - MEC code distribution for USS GEORGE WASHINGTON

Technicians at the Navy Inventory Control Points can routinely provide part-worth digits p . In fact, our system is now in use by the Navy [4] . There is every reason to believe that the general approach and methodology of present Polaris MEC system could readily be adapted to other weapons systems.

References

[1] Marvin Denicoff, Joseph P. Fennell, and Henry Solomon, "Summary of a method for determining the military worth of spare parts", Naval Research Logistics Quarterly, vol. 7 (1960), pages 221-234.

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35p.

(40)

DEPARTMENT OF THE NAVY
OFFICE OF THE CHIEF OF NAVAL OPERATIONS
WASHINGTON, D.C. 20350

IN REPLY REFER TO
OPNAVINST 4441.12A CH-2
OP-412C
1 Aug 197[illegible]

OPNAV INSTRUCTION 4441.12A CHANGE TRANSMITTAL 2

Subj: Supply Support of the Operating Forces

Encl: (1) Revised page 5 and reprinted page 6 to enclosure (3)

1. Action. Addressees are requested to make the enclosed change.

E.A. Grinstead
E. A. GRINSTEAD, JR.
By direction

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IN REPLY REFER TO
OPNAVINST 4441.12A CH-1

3 MAR 1975

OPNAV INSTRUCTION 4441.12A CHANGE TRANSMITTAL 1

Subj: Supply support of the Operating Forces

Encl: (1) Revised enclosure (3) to basic instruction

1. Purpose. To promulgate change 1 to the basic instruction.

2. Action. Addressees are requested to make the enclosed change.

of Naval Operations

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IN REPLY REFER TO
OPNAVINST 4441.12A
Op-412C
3 AUG 1973

OPNAV INSTRUCTION 4441.12A

From: Chief of Naval Operations

Subj: Supply support of the Operating Forces

Ref: (a) OPNAVINST 4000.57C of 4 Aug 1972
(b) OPNAVINST C4080.11A of 4 Oct 1971 .11B 4/21/77 OP-41C
(c) BUMEDINST 6700.13D of 9 Feb 1968

Encl: (1) Shipboard Stock Levels
(2) Criteria for Shipboard Allowances
(3) Criteria for Mobile Logistic Support Force (MLSF) Loads
(4) Criteria for Overseas Base Stocks
(5) Aeronautical Supply Support
(6) Identification of Acronyms

1. Purpose. To state basic Navy policy governing the determination of fleet materiel requirements in support of installed equipments and systems, and the distribution of fleet materiel assets, and to prescribe the shipboard stock levels necessary to achieve the required standards of logistics readiness of the Operating Forces.

2. Cancellation. OPNAVINST 4440.21 of 17 Nov 1968 and OPNAVINST 4441.12 of 27 Aug 1964 are hereby canceled.

3. Scope. This instruction applies to all materiel other than ammunition and bulk petroleum carried in, or specifically positioned for, the use of the Operating Forces, except Fleet Ballistic Missile (FBM) submarines and tenders which are governed by reference (a). It encompasses materiel carried by forces afloat, including Marine Aircraft Groups (MAGs), and ashore (CONUS and overseas). The guidance contained in this instruction applies as well to those commands and activities participating in, or responsible for, the development and maintenance of allowance lists and load lists and specifying stock levels.

4. Objective. To provide a level of supply aboard ships, in the Fleet Marine Forces (FMFs), and at sites supporting

operating forces which is compatible with approved maintenance concepts, projected replenishment capabilities, readiness objectives, and available funding for naval operations in support of national policy, for the period specified by the Navy Support and Mobilization Plan (NSMP). Maintenance of a balanced, ready force, capable of performing the Navy's mission of strategic deterrence, sea control, projection of power, and overseas presence in the face of steadily increasing costs of sophisticated weapons systems continues to make it imperative that effective management techniques be employed governing the utilization of materiel assets. The concept for attaining these support objectives is as follows:

a. Organic Level of Supply. This includes allowances or levels of materiel authorized for stock to sustain operations under specified maintenance concepts for a stated period. Such materiel, when not in excess of authorized levels, is normally not subject to redistribution by a central inventory manager, except in emergencies and subject to approval of the applicable Fleet Commanders in Chief (CINCs).

b. First Echelon of Resupply. This includes the materiel positioned in ships of the MLSF. MLSF load lists include the materiel requirements and support the readiness objectives of the Fleet Support Element of CNO Special Project HURRICANE/TYPHOON, prescribed by reference (b). There is no first echelon of resupply for aviation peculiar materiel.

c. Second Echelon of Resupply. The second echelon of resupply, or the wholesale system, is that materiel held at supply centers, supply depots, air stations, weapon stations, and shipyards for resupplying the Operating Forces. It includes materiel located at, but excess to, that authorized for the organic level and first echelon of resupply when such materiel is financially reportable in two digit stores accounts and/or considered in the budget submission of central inventory managers.

5. Policy. The following basic policies apply to the development of authorized allowances, load lists, stock levels, and the management of inventories positioned in support of the Operating Forces.

a. Primary reliance for supply support of self-deployable naval units will be placed on the organic level of supply, based upon the criteria specified in the attached enclosures.

b. First echelon resupply stocks afloat will consist of repetitively demanded (demand based) items which are required to support installed equipments and systems and embarked personnel. Low-demand items may also be included to reduce reaction time for equipments experiencing unusual readiness problems. CNO (Op-04) will review and approve those equipments nominated for augmented support. Deployed units will utilize the afloat support capability of MLSF units to the fullest extent practicable.

c. Individual items of a low-demand nature as defined in enclosure (2), paragraph 4b, may be stocked in either the organic or first echelon but, insofar as practical, not at both.

d. Stockage objectives will be applied to demand based items and will be specified in days of supply for safety and operating levels. The average endurance level is normally considered to be the safety level plus half the operating level. In assessing the readiness of individual ships for a particular operation, a ship's average endurance level and its past and future resupply opportunities should be among the areas critically reviewed.

e. Management of repairable items will be given special emphasis in accordance with the policy guidance contained in separate directives.

f. Low-demand items will be included in authorized allowances at the organic level, based upon effectiveness objectives and criteria specified in the attached enclosures.

g. Stocks which are financially reportable in two digit stores accounts and/or considered in the budget submissions of central inventory managers are subject to shipment directives of the Inventory Manager (IM) when excess to authorized levels and necessary to fill firm requirements, but not available elsewhere in the wholesale system.

h. New or unstable equipments will be supported in accordance with normal stocking criteria and resupply techniques, except where the need for special support procedures are indicated and agreed to by applicable Fleet CINCs.

i. Application by the ship or activity of variable safety and operating level techniques which recognize economic

considerations and risk of stockouts are required where financial support and management systems permit implementation.

j. The depth of allowance and retail stock levels for new items identified through the provisioning process will be constrained by the guidance contained herein. It is recognized that temporary degradation of support may result pending development of local demand patterns.

k. Establishment of new first or second echelon resupply capability at overseas activities will be reviewed and approved by CNO (Op-04) in advance of the establishment of such capability. Fleet CINCs will provide justification for such proposed actions,based upon economic considerations and/or readiness objectives. When approved, the resupply responsibilities will be prescribed in the approved missions of the applicable overseas activities and units.

l. Responsible commands will obtain CNO (Op-04) approval for deviations from policies and guidance contained in this instruction.

m. CNO will approve Pre-positioned War Reserve Requirements (PWRR). Fleet Issue Load List (FILL) materiel identified as Pre-positioned War Reserve Stock (PWRS) and positioned by the Fleet CINCs may be issued to meet peacetime requirements, but should be replaced at the earliest practical date after issue.

6. Action

a. The Chief of Naval Material will:

(1) Coordinate and administer the development, maintenance and revision of shipboard, aviation and MAG allowance lists and load lists to include the

(a) establishment of procedures for collection of fleet demand data;

(b) establishment of procedures for recommending changes in shipboard, aviation and MAG allowances;

(c) establishment of procedures for control and justification of the addition and deletion of items of a technical override (TOR) nature to authorized allowance and load lists within the framework of guidance contained in this instruction;

(d) determination of the degree to which MLSF loads will be augmented to provide equipment support, based upon requirements of the Fleet CINCs and in accordance with the criteria prescribed in enclosure (3);

(e) assignment of military essentiality codes based upon guidance provided by CNO;

(f) coding of allowance lists to identify items as equipage, repair parts or consumables and to reflect military essentiality wherever practicable.

(2) Provide program management and support of the Supply Operations Assistance Program (SOAP), both ship and aviation.

(3) Establish and promulgate criteria for the identification of high unit value, high unit cube or items in critical supply position which require modified or restricted asset distribution for resupply support of the Operating Forces, including the identification and designation of air-worthy items based upon economic analysis.

(4) Monitor MLSF and advance base inventories through the media of financial, inventory and effectiveness reports submitted by the Fleets and recommend needed action to CNO and appropriate Fleet CINCs.

(5) Establish procedures for maintaining visibility of stocks afloat and ashore, and monitoring and utilization of excesses as directed by CNO. In this regard, it is intended that the separate identity of operating forces requirements (allowances) and assets (materiel on hand/on order), and those of the wholesale system be maintained, and that procedures applicable to afloat assets be coordinated with Fleet CINCs.

(6) Establish, in coordination with the Fleet CINCs, stocking criteria for demand based items in base operating stocks positioned overseas to ensure compatibility with funding constraints.

(7) Develop procedures to utilize overseas stocks to fill urgent requirements, and monitor periodic purges of Appropriation Purchases Account (APA) and Navy Stock Account (NSA) excesses afloat and ashore.

(8) Evaluate the effectiveness of overall supply support to the Operating Forces, including an analysis of Coordinated Shipboard Allowance List (COSAL) and Aviation Consolidated Allowance List (AVCAL) performance, based on the actual experience of designated ships and MAGs, and recommend or initiate action to correct deficiencies and implement improvements, as appropriate.

b. The Chief of Naval Training and the Chief, Bureau of Medicine and Surgery will:

(1) Develop and review allowance and load lists for materiel under their technical and management control in accordance with procedures established by the Chief of Naval Material. Since the authorized medical and dental allowance list is based on combat support requirements rather than generated demand, reference (c) will control these listings.

c. The Fleet Commanders in Chief will:

(1) Provide for the collection and reporting of fleet demand data to be used in the development and revision of shipboard, aviation and MAG allowance lists and load lists, in accordance with procedures established by the Chief of Naval Material.

(2) Utilize allowance lists as the basic stocking authority at the shipboard and MAG level.

(3) Enforce allowance list and load list discipline to ensure that stocks are maintained at prescribed levels.

(4) Provide for the submission of logistic intelligence and support requirements to the Chief of Naval Material, SYSCOMHQ and IMs, as appropriate, for use in the development, maintenance and revision of allowance lists and load lists, including:

(a) requirements for the distribution of high unit value, high unit cube and items determined to be in a critical supply position required for support of the Fleet;

(b) the planned distribution of the FILLs;

(c) requirements for support augmentation to the FILL;

(d) requirements for quarterly addenda to the FILL;

(e) the specific hulls and/or types of ships to be supported by specific tenders and repair ships;

(f) load list requirements necessitated by special situations or missions; and

(g) the 5 year aircraft deployment schedule updated semi-annually or as major changes occur.

(5) Conduct the Supply Operations Assistance Program (SOAP).

(6) Provide for the submission of transaction, financial, inventory and effectiveness reports on designated ships and overseas base inventories to the Chief of Naval Material.

(7) Establish the levels of base operating stocks required at overseas bases to support approved missions in accordance with Chief of Naval Material criteria.

(8) Recommend PWRR to CNO (Op-04), in accordance with reference (b).

(9) Establish and approve Fleet Program Support Materiel (FPSM) requirements in accordance with the criteria prescribed in enclosure (4). Proposed FPSM requirements not meeting specified criteria, but which are fully supported by the Fleet CINC, shall be forwarded to CNO (Op-04) for approval.

(10) Submit recommended changes to policies and guidance contained herein to CNO (Op-04).

7. Implementation. Two copies of all instructions and notices implementing this instruction will be provided to CNO (Op-04).

W. D. GADDIS
Deputy Chief of Naval Operations
(Logistics)
By direction

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SHIPBOARD STOCK LEVELS

1. Purpose. This enclosure prescribes general policy for the range and depth of materiel to be carried by individual ships to insure compatibility with readiness objectives, resupply concepts, and a safety factor for independent operations in an environment of isolation and limited resupply capability.

2. Scope. This enclosure applies to the following categories of materiel: spares, repair parts, consumables, provisions and ship's store stock related to installed equipment and embarked personnel for forces afloat.

3. Policy

a. For the allowed range of materiel (see enclosure (2)), the depth of designated categories of materiel will be computed to achieve the stock levels shown below. Development of stock levels of materiel for new classes of ships shall be coordinated with CNO (Op-41).

INVENTORY OBJECTIVES

Spares, Repair Parts and Equipment Related Consumables

SHIP TYPE	SL1/	OL2/	SO3/	AEL4/	RO5/ FILL ITEMS 6/	RO5/ NON-FILL7/ ITEMS	RO5/ AIR8/ WORTHY ITEMS
ALL, EXCEPT NON-SELF SUSTAINING9/	60	30	90	75	120	180	120
NON-SELF SUSTAINING9/	AS REQUIRED TO ACCOMPLISH ASSIGNED MISSION						

Non-Equipment Related Consumables, Ships Store Stock, Clothing & Small Stores and Provisions

SHIP TYPE	SL1/	OL2/	SO3/	AEL4/	RO5/ FILL ITEMS 6/	RO5/ NON-FILL7/ ITEMS	RO5/ AIR8/ WORTHY ITEMS
CARRIERS	45	30	75	60	105	165	105
CRUISER/DLGN/DLG	30	30	60	45	90	150	90
DDG/DEG/DD/DE	10/	10/	45	10/	75	135	75
AD/AR/AS	60	30	90	75	120	180	120
SUBMARINES	60	30	90	75	120	180	120

SHIP TYPE	SL1/	OL2/	SO3/	AEL4/	FILL ITEMS 6/	RO5/ NON-FILL7/ ITEMS	AIR8/ WORTHY ITEMS
AMPHIBIOUS							
Ship Complement	45	30	75	60	105	165	105
Embarked Troops	30	30	60	45	90	150	90
SERVICE FORCE	45	30	75	60	105	165	105
NON-SELF SUSTAINING9/	AS REQUIRED TO ACCOMPLISH ASSIGNED MISSION						

1/ SAFETY LEVEL (SL). This is the quantity of materiel in addition to the operating level, required to be on hand to permit continuous operations in the event of interruption of normal replenishment, or unpredictable fluctuations, in issue demand.

2/ OPERATING LEVEL (OL). This is the quantity of materiel (exclusive of SL) required to sustain operations during the interval between successive requisitions.

3/ STOCKAGE OBJECTIVE (SO). This is the maximum quantity of materiel to be maintained on hand to sustain current operations; it includes the sum of stocks represented by the SL and the OL. It equates to the days' endurance for a given ship type.

4/ AVERAGE ENDURANCE LEVEL (AEL). This is the average quantity of materiel normally required to be on hand to sustain operations for a stated period without augmentation; it includes the sum of stocks represented by the SL and one-half the OL. AEL in terms of days of supply is used for the purpose of operational planning.

5/ REQUISITIONING OBJECTIVE (RO). This is the maximum quantity of materiel to be maintained on hand and on order to sustain current operations; it includes the sum of stocks represented by SL, OL and order and shipping time (OST).

6/ Includes resupply items from AS load.

7/ The OST for non-FILL items will be set at 90 days or actual experience, whichever is less.

8/ Air worthy items are those items designated for outbound movement by air, based on economic considerations. (While individual coding of airworthy items has not been implemented as of the publication date of this instruction, future directives will provide guidance and require such an identification in appropriate publications, catalogs, files, etc.).

9/ Landing craft, patrol gunboats, etc., of less than 1,000 tons displacement.

10/ As may be designated by Fleet CINCs.

b. The inventory objectives outlined above are designed to provide necessary endurance capability for ships and units operating in an environment of little or no replenishment opportunity, for which the Fleet must be prepared. Replenishment/reordering actions must be initiated on at least a biweekly basis to maintain an acceptable readiness level for those items not routinely scheduled for an underway replenishment. Recognition must be given to the fact that more than 40% of repair parts requirements are not available at the organic level and must be provided by frequent and expedited methods.

c. The requisitioning objectives described above will apply to deployable forces, unless a lesser OST is authorized by Fleet CINCs when operating from CONUS ports or adjacent to overseas depots. Fleet CINCs have authority to modify the above objectives to correlate with operating environment and storage space.

d. The stockage objectives described above are applicable, in a practical sense, only to demand based items and endurance projections must be judged accordingly.

e. The stockage objectives described for provisions represent a composite objective for individual categories, i.e., freeze, chill and dry. Space permitting, stockage levels for dry provisions may be increased to equal, but not exceed, those specified for repair parts.

f. It is desirable for ships to deploy fully topped-off to meet the stockage objectives prescribed in paragraph 3a of this enclosure, even though topping-off is neither normal procedure, i.e., replenishment should be generated only when triggered by reaching the item reorder point, nor is it provided for in funding and staffing considerations. However, the necessity for avoiding depletion of MLSF and advance base stocks by newly arriving ships makes topping-off desirable to the degree that resources will allow.

CRITERIA FOR SHIPBOARD ALLOWANCES

1. Purpose. This enclosure prescribes policy for the development and maintenance of shipboard allowances of materiel (less FBM submarines and tenders) necessary to achieve the required standards of logistic readiness and endurance of the Operating Forces.

2. Scope. This enclosure applies to all items listed in the COSAL for individual ships.

3. Policy

a. The COSAL is an authoritative document which lists the equipments, components, repair parts, consumables, and operating space items required for an individual ship to perform its operational mission. The COSAL indicates the items (and quantity of each item) which an individual ship should have onboard to achieve a self-supporting capability for an extended period of time. The materiel allowances prescribed in the COSAL constitute the organic level of supply.

b. In normal circumstances, shipboard allowances are mandatory as to range and depth of materiel carried. However, the following general exceptions to this policy are authorized:

(1) Fleet CINCs may authorize, for an interim period, shipboard loading of materiel in excess of allowance to meet unusual situations, such as:

(a) Extended ship deployments of a non-routine nature to areas where support from the MLSF or other replenishment sources is impracticable;

(b) Non-routine ship operations employing weapons systems for which support from the MLSF or other replenishment sources is not planned; and

(c) Other extraordinary circumstances.

(2) The range and depth of allowance materiel may be changed at the shipboard level in accordance with stockage criteria prescribed by approved shipboard procedures and as authorized by Fleet CINCs for utilization of variable

operating and safety levels and for intensive inventory management of special items (e.g., Selected Item Management (SIM) and non-SIM procedures, etc.).

(3) Replacement of repair parts for ships officially designated for inactivation or to be stricken from the Naval Register should be reduced or terminated in consonance with the period of remaining employment anticipated. Modified materiel support will be accomplished by adjustments to shipboard stockage objectives and/or mass requisition cancellations.

(4) Mandatory range and depth may be reduced as necessitated by funding constraints.

c. Proposed changes in allowance will be submitted by the originating ship in accordance with procedures established by the Chief of Naval Material.

d. COSALs and actual stock levels will be responsive to changes in demand, as reflected in approved programs for collection of data. As a minimum, COSALs will be reviewed and revised incident to the ship's regular maintenance overhaul. The Supply Operations Assistance Program (SOAP) normally will be conducted concurrent with the regular maintenance overhaul, during which time the best demand history available will be used to refine inventories, update inventory records, and identify and process materiel deficiencies and excesses. Between SOAPs, an allowance document, such as an Allowance Parts List (APL) should be provided to support newly installed equipments.

e. When an item is not included in the allowance because of high unit cost, total cost, weight, size, or other considerations, the allowance list preparation activity shall initiate action to position assets with the MLSF or at selected ashore locations in order to provide rapid response to expected fleet demands.

4. Criteria. The following criteria will be used in the development of a shipboard allowance list for those items within the installation capability of the organic unit.

a. [redacted] (i.e., items having an historical or predicted demand of [redacted] units in [redacted] for all shipboard equipment applications):

(1) The range of demand based items will consist of all items meeting this qualification criteria.

(2) The [redacted] items will be sufficient to satisfy [redacted] by the ship in a 90 day period. (The 90% availability criterion established for demand based items is higher than the overall 85% availability goal cited in paragraph c, below, in recognition of the shortfall between the theoretical effectiveness which the COSAL computation model provides using system-wide demand factors, and the actual demand experience which the ship will encounter.) Depth computations will be predicated on combat consumption rates wherever such rates can be accurately ascertained.

b. [redacted] (i.e., items having an historical or predicted [redacted] for all shipboard equipment applications):

(1) The range of low-demand items will consist of those which qualify under the following restrictions:

(a) [redacted]

(b) [redacted] TORs to the low-demand item selection criteria prescribed above will be added to shipboard allowance lists only in exceptional circumstances, to insure safety and preservation of life of personnel, or where lack of the item will cause total degradation of a capability essential to a primary mission of the ship. These exceptions will be documented and supported in accordance with procedures established by the Chief of Naval Material.

(2) [redacted]

c. The objective for overall COSAL performance is to fill from onboard stocks 65% (gross effectiveness) of all

demands and to provide an overall availability for items allowed of 85% (net effectiveness).

d. Shipboard allowance lists will reflect the military essentiality of each item, wherever practicable.

e. Shipboard allowance lists will be coded to identify items as equipage, repair parts, or consumables, and also to indicate, where applicable, the degree of management control required aboard ship (e.g., custody signature required).

f. Repair parts included in shipboard allowance lists will be assigned allowance derivation codes to identify the basis for shipboard stockage (e.g., demand based, technical override, planned maintenance requirement, etc.).

CRITERIA FOR MOBILE LOGISTIC SUPPORT FORCE (MLSF) LOADS

1. Purpose. This enclosure prescribes policy for the development and maintenance of inventory levels for the MLSF.

2. Scope. This enclosure applies to the positioning, maintenance and management of materiel (except ammunition and bulk petroleum) carried in MLSF ships (less FBM tenders) for the support of other Fleet units.

3. Policy.

a. Materiel requirements for resupply support of deployed forces and augmented forces to be deployed will be determined through the development of Fleet Issue Requirements Lists (FIRLs), as described in reference (b), Tender and Repair Ship Load Lists (TARSLLs), AO deck loads, subsistence load lists, tailored loads (HULL), ships store load lists and authorized afloat and ashore supplements as described in reference (b). TARSLLs, materiel positioned afloat as AD/AR/AS load lists, are designated as PWRS in accordance with reference (b).

b. Fleet Issue Load Lists (FILLs) will be developed to reflect that portion of the total FIRL that is to be positioned afloat as PWRS, as prescribed in reference (b). AO deck load PWRS is stocked ashore at strategic locations, as determined and designated by the Fleet CINCs, in accordance with reference (b). AO deck loads afloat are peacetime operating stock (POS).

c. In addition to the PWRS FILL and TARSLL quantities, a POS level will be established for peacetime support to provide a reasonable assurance that PWRS materiel will be available to meet contingency requirements. POS levels will be computed by the load carrying ship and reviewed as directed by the Fleet CINCs, but no less frequently than once per quarter.

d. The inventory level of stores account material, specified in FILLs and TARSLLs positioned in load carrying ships, will be closely monitored by Fleet CINCs in order to achieve and maintain a high state of logistic readiness

of the Fleet within the framework of the guidance in this instruction. To this end, a management information system capable of providing accurate, current and comparable inventory and financial data will be developed and maintained. The Stores Account Material Management Afloat/Ships Authorize Level (SAMMA/SAL) concepts and procedures provide the visibility to monitor the inventory and financial management of MLSF ships. Semiannually, by 15 January and 30 June, Fleet CINCs will submit SAMMA/SAL reports to CNO (OP-04), with copies to COMNAVSUPSYSCOM, FMSO and SPCC. The SAMMA/SAL report will stratify the authorized investment levels for both on hand and on order categories, current on hand and on order assets, and authorized and unauthorized long supply in both on hand and on order status. The afloat inventories will be stratified separately by category of investment, i.e., FILL/PWRS, COSAL, and POS. Further, the report will reflect the above stratifications by budget project for NSF materiel and by cognizance symbol for APA materiel. The format of the semiannual report will be as follows: (1) A total Fleet summary report; (2) an individual report for each load carrying ship; and (3) appropriate explanations for the causes of unauthorized long supply or on order for any NSF budget project or APA cognizance symbol materiel so effected. The explanation will also include the ships responsible for the unauthorized assets and corrective actions planned or taken. COMNAVSUPSYSCOM will subsequently provide an analysis of the SAMMA/SAL and Financial Inventory Reports (FIR) to CNO (OP-04) relating the impact of any excess investments on stock fund or APA budgets.

e. Routine resupply of ships of the MLSF from shore activities will be provided only by activities rendering transaction item reports to Navy Inventory Managers.

f. Where high unit cost, high unit cube, or a critical supply situation prevent materiel distribution to applicable MLSF ships, the stocking of such items may be limited to a designated ship or overseas activity at the discretion of the appropriate Fleet CINC, and in coordination with the Inventory Manager.

g. Fleet CINCs, in conjunction with the Chief of Naval Material, are authorized to position other stores account materiel in ships of the MLSF. Designation of AO deck loads, subsistence load lists, tailored loads and ships store stock load lists are contained within the scope of this authority. Such materiel will be considered peacetime stocks.

h. In conjunction with the industrial overhaul of load carrying ships, the load list inventory will be refined, the inventory records up-dated, and materiel deficiencies and excesses identified and processed.

4. Criteria for MLSF Load Lists.

a. Combat Stores Ship (AFS). An AFS load will be constructed to provide resupply support for items in demand by the Fleet, less items peculiar to submarines and Navy managed aviation cognizance materiel, and will consist of a FILL and POS level. The FILL range and depth are the minimum levels to be stocked and are mandatory.

(1) Afloat FILLs will be developed to reflect that portion of the FIPL that is to be positioned in a combat stores ship (AFS), as prescribed in reference (b).

(2) A POS level consisting of a combined 60 day Operating and Safety Level for demand based items and actual Order and Shipping Time is authorized. Increases in these levels will be approved by CNO (OP-04), based upon Fleet recommendations. Item selection criteria and variable level techniques may be applied to peacetime levels to constrain workload and to increase total load effectiveness at Fleet Commander discretion. A maximum retention level of six months is authorized for items where changing demand patterns generate long supply.

(3) Actual O&ST will include (1) requisition transmission time, (2) requisition processing time, and (3) shipping time. It will exclude (1) other than usual requisition priorities, (2) other than usual transportation modes, and (3) a stockout at supply sources. It is recommended that Fleet CINCs review and control the O&ST values applied.

b. TARSLL. TARSLLs will be constructed to support the industrial mission (and, in the case of non-FBM submarine tenders (AS), the resupply mission) of each tender or repair ship. Based upon the scope of maintenance support to be provided by each tender or repair ship, as reflected in support requirements provided to the Chief of Naval Material by the Fleet CINCs, TARSLLs will be classified as either "hull tailored" or "ocean tailored". Hull tailored TARSLLs will be constructed to support specific hulls assigned for support to a specific tender or repair ship (e.g., AS-16 TARSLL for support of assigned submarines). Ocean tailored TARSLLs will be constructed to support specific hull types and positioned in all tenders or repair ships of one of the

Fleets (e.g., AD TARSLL for the Pacific Fleet for support of designated ship types). The range and depth of TARSLLs are mandatory except for local, demand based range additions, and permissive stocking of industrial related items as covered in paragraph 4b(3), below. Detailed criteria for TARSLL development are as follows:

(1) TARSLLs will be developed on the basis of shipboard equipment configuration of the ships being tended, technical failure rates and peacetime demand of the active fleet tenders and repair ships, using demand data collection procedures established by the Chief of Naval Material. Peacetime demand will be adjusted to reflect combat consumption rates for appropriate items, wherever such rates can be accurately ascertained.

(2) TARSLLs will be composed of the following general categories of items:

(a) Equipment related items - Items required by the tender or repair ship to perform the maintenance support function for equipments/components installed in the ships being tended;

(b) Industrial related items - General use items required to support the maintenance shops in a tender or repair ship; and

(c) Resupply materiel - In the case of submarine tenders (AS), materiel required to support the resupply of assigned submarines.

(3) CNO (OP-04), in coordination with the Fleet CINCs, will prescribe specific parameters for simulating alternate TARSLLs based on the variable factors of component cutoff (see (a) below) and quarterly average demand (see (b) below) for review by the cognizant Type Commanders. Final determination of TARSLL range rests with CNO (OP-04).

(a) Component Cutoff - In analyzing equipment related items as candidates for inclusion in the range of materiel in ocean tailored TARSLLs, consideration will be given to the degree of commonality of equipment configuration in the mix of ships to be tended. In order to be included in the authorized range of materiel, range candidates of equipment related items will have equipment application in a minimum number of tender ships, as well as prescribed by CNO in coordination with the Fleet CINCs.

(b) Quarterly Average Demand (QAD) - In order to be included in the authorized range of materiel, range candidates of equipment related items will meet specific demand frequency in time criteria determined by CNO (OP-04).

(c) Equipment related items which cannot be installed by tender or repair ship maintenance personnel will be excluded from the TARSLL.

(d) Range candidates of industrial related items in a generic class of materiel (e.g., lumber, bar stock, etc.) may be tailored, by means of discretionary stockage, to reflect the maintenance philosophy and shop practices of specific tenders or repair ships.

(e) Requirements for support of special missions or situations will be submitted to the Chief of Naval Material by the Fleet CINCs.

(4) The depth of materiel in each TARSLL will be sufficient to satisfy, for those items included in the TARSLL range, 85% of the requisitions reflected in the demand/data base for a 90 day period. The depth of equipment related items will not be less than the minimum replacement unit.

(5) Peacetime Operating Stock levels for demand based items, consisting of a combined 60-day Operating and Safety Level for TARSLL Load List items and a combined 90-day Operating and Safety Level for locally determined range additions, are authorized. Increases in these levels will be approved by CNO (Op-04), based upon Fleet recommendations. Item selection criteria and variable level techniques may be applied to peacetime levels to constrain workload and to increase total load effectiveness at fleet commander discretion. A maximum retention level of six months is authorized for items where changing demand patterns generate long supply. (R

(6) Actual Order and Shipping Time will be utilized in establishing requisitioning objectives. Requisition transmission, processing, and shipping time will be included. The compilation of actual O&ST factors will exclude data involving other than usual requisition priorities and transportation modes and the extended leadtime involved where the supply source is out of stock. It is recommended that Fleet CINCs review and control the O&ST values applied. (R

(7) TARSLLs will normally be updated on a 3 year cycle unless otherwise requested by Fleet CINCs on the basis of significant change in hull mix or equipment configuration. At the time of updating, the best demand history available will be used to refine the load list inventory, update inventory records, and identify additions and deletions to the range and depth of the load.

(8) Items new to the system and considered as candidates for interim changes to existing TARSLLs for ADs and ARs must be those items coded for intermediate level maintenance. To qualify, the item must meet the current component cut criteria. Items that qualify will be stocked in the deployed tender and repair ships, only.

c. Other Load Lists. Included in this category are AO deck loads, provision load lists, tailored loads and ships store stock load lists. Range and depth will be a Fleet CINC determination made in coordination with the Chief of Naval Material and will be considered mandatory.

CRITERIA FOR OVERSEAS BASE STOCKS

1. Purpose. This enclosure prescribes policy for the stockage, management and control of supply inventories positioned at overseas bases.

2. Scope. This enclosure applies to overseas base stocks. Specifically excluded are stocks procured by the Navy Industrial Fund.

3. Policy

a. Overseas base stocks will consist of the materiel required to support the approved mission(s) of an individual base under the concept and constraints outlined. This includes Base Operating Stock, PWRS and FPSM.

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b. Overseas base stocks (all categories) will be reported in normal financial accounting and budget submissions. Asset visibility and control will be as prescribed by the Chief of Naval Material, in coordination with the Fleet CINCs, based upon CNO guidance.

c. The Chief of Naval Material will prescribe techniques and methodology for displaying requirements and assets to separately identify the various categories of materiel described herein for budget and analysis purposes.

d. Budget submissions will include known future lay ins of initial stocks to support mission essential equipments to be installed at overseas bases.

e. Overseas base stocks are subject to Transaction Item Reporting (TIR) to Navy IMs when prescribed by Chief of Naval Material in coordination with the Fleet CINCs. Such stocks will be considered to be a part of IM's authorized levels.

f. Items carried in base operating stocks will not be duplicated with FPSM and additional depth will not be provided for the items.

4. Criteria. The following criteria will be used in the identification and designation of overseas base stocks.

a. Base Operating Stocks will consist of the materiel required to support shipboard, aeronautical and shore based

equipment and systems, rolling stocks, industrial mission and assigned personnel. Base operating stocks are authorized as follows:

(1) Demand based items with a frequency of demand criteria as specified by Chief of Naval Material.

(2) Stock levels for demand based items will be constrained to not more than an average inventory level (SL plus one-half of the OL) of 90 days and a maximum of 90 days or actual OST, whichever is less. When supporting rationale is documented and authorized by applicable Fleet CINCs, higher levels may be maintained. A copy of authorized exceptions will be provided to CNO, CHNAVMAT and applicable IMs.

(3) Low-demand items are not authorized for base operating stocks. If low demand items are required for mission essential equipments and systems, they will be designated FPSM.

b. PWRS, as recommended by the Fleet CINCs and approved by CNO, is authorized in accordance with reference (b).

c. FPSM is authorized as follows:

(1) Materiel required to support the installation and operation of a new mission essential equipment or system in advance of actual installation and operation.

(2) Materiel required to support a resupply mission for newly installed shipboard and aviation equipment or systems in advance of anticipated demand. This will not duplicate FILL materiel positioned in ships of the MLSF or ashore.

(3) Materiel designation and categorization will be confined to new items not presently carried in base operating stocks. Initial positioning action will be based upon quantity recommendation of the allowance preparing activity with the approval of the Fleet CINC, based upon criteria contained herein. The range and depth of FPSM items will normally be determined from an allowance list.

(4) Identification and approval of mission essential equipment support qualifying for FPSM and advanced positioning of materiel must be approved by the applicable Fleet CINC.

(5) The demand development period authorized for FPSM will be one year from installation or operational date, but may be extended in writing by the Fleet CINC to two years if the operating environment or essentiality so dictates. The FPSM designation will be discontinued for those items which have become demand based during the one-year demand development period, regardless of the new demand based quantity.

(6) FPSM requirements will be limited to standard stock materiel, i.e., the item must have an assigned Federal Stock Number or Activity Control Number.

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d. Excess/Long Supply. Those stocks which are excess to prescribed base operating stock levels and initial FPSM stocks which no longer qualify as required by Fleet CINCs for support of mission essential equipment will become excess/long supply stocks, excluding economical retention levels authorized by Fleet CINCs.

AERONAUTICAL SUPPLY SUPPORT

1. Purpose. This enclosure prescribes policy for the development and maintenance of allowances of aeronautical materiel necessary to achieve the required standards of logistic readiness of the operating forces predicted on the maintenance plan and repair capability for the site under consideration.

2. Scope. This enclosure applies to all items listed in the AVCAL and other related allowances for individual ships, Marine Aircraft Groups (MAGs) and shore activities (CONUS and overseas) supporting aircraft.

3. Policy

a. The basic concept for identification and categorization of stocks required to support fleet aircraft is as follows:

(1) Requirements and/or materiel procured and/or positioned in accordance with the guidance contained herein will be separately identified by IM in budget and stratification submissions.

(2) Assets in excess of the quantities prescribed herein will be considered as wholesale stocks, unless the materiel is positioned afloat.

(3) Materiel procured in accordance with reference (b) will be designated as PWRS.

b. The AVCAL is an authoritative document which lists the components, repair parts and consumable items required for a ship, MAG or shore activity to perform its operational mission in support of assigned aircraft, with consideration for available organic repair capability. The AVCAL includes the items (and quantity of each item) which should be on board to achieve a self-supporting capability for a prescribed period of time. The materiel allowances prescribed in the AVCAL and other related allowance documents constitute the organic levels of supply applicable to aeronautical materiel for support of aircraft afloat and ashore.

c. AVCALs will be constructed from Initial Outfitting Lists (IOLs) and inputs of APL or Allowance Equipage List (AEL) items from IMs that apply to the aircraft and equipments to be supported. Items applicable to the Maintenance Support

Package (MSP) concept will be included in the official AVCAL. Unique AVCALs may be designed to support special programs on non-aviation ships, such as the Light Airborne Multi-Purpose System (LAMPS) or airborne mine countermeasures detachments.

d. In normal circumstances, the AVCAL is mandatory as to range and depth of materiel carried, except as may be adjusted upward for consummables based on local demand rates. However, the range and depth of allowance materiel may be modified by Fleet CINCs in order to meet unusual situations and to compensate for local maintenance conditions or application of variable operating and safety level concept. The decision to modify range and depth levels must be coordinated with the IM to assure that Weapons System Planning Data (WSPD) revisions are sequenced with budgeting adjustments to assure adequate follow-on support.

e. Basic factors upon which allowance lists are developed will be responsive to changes in maintenance capability and usage resulting from approved data collection programs. The inclusion of an item in an allowance list will be based on rates representing planned maintenance action, i.e., intermediate or organizational level repair. Factors assigned to newly introduced items will be based on average failure rates for items in analogous nomenclature, group and class categories; those for established items will be based on historic usage. Items not qualifying for inclusion on the basis of rates cited above will be excluded from allowance lists, except in instances where documented and approved in accordance with procedures established by the Chief of Naval Material. Basic data collection systems will include an historical demand file for carrier and MAG deployments to facilitate purging of candidate files for non-moving items. As a minimum, AVCALs will be reviewed and revised incident to Regular Overhaul/ Restricted Availability (ROH/RAV) schedules or prior to each carrier deployment. MAG AVCALs will be reviewed and revised periodically as determined by the air type or FMF commander, but not less often than every 18 months or prior to deployment. The Supply Operations Assistance Program - Aviation (SOAP-A) normally will be conducted concurrent with the ROH schedule for carriers. Air type commanders, in conjunction with FMF commanders, will develop procedures for conducting SOAP-A for MAGs concurrent with the periodic AVCAL review. Revised AVCALs will be provided to shore activities supporting aircraft at least every two

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years, or more frequently if required by changes in supported aircraft, installed equipment, or ground support equipment. Excesses will be determined based upon prescribed allowances and retention levels. Materiel so identified will be returned to the supply system at every available opportunity in accordance with existing instructions.

f. AVCAL scheduling for afloat units including MAGs, about to deploy must be planned to allow for constructing the AVCAL and for the IM to introduce requisitions into the supply system in time to have materiel in place 30 days ahead of date aircraft are due to operate from the assigned ship or new site. The objective is to allow 90 days for shipping, receiving, staging, storage and recording materiel receipts.

g. The capability to provide effective and responsive resupply is essential to aircraft readiness. Carrier Onboard Delivery (COD) support will be utilized to the fullest extent practicable. The use of the MLSF to position technical aviation stocks is not normally considered to be an economical, effective or efficient use of assets.

h. Issues from rotatable pools will be included in financial inventory reports to provide budget support for the pool investment.

i. The Chief of Naval Material will prescribe techniques and methodology for displaying requirements and assets to separately identify the various categories of materiel described herein for budget stratification and analysis purposes.

4. Criteria. The following criteria will be used in the development of range and depth of individual allowance lists for ships, MAGs and other activities supporting aircraft. The range and depth of stock will be ascertained by reference to applicable IOLs/APLs/AELs for the purpose of establishing the quantities to be carried.

a. Demand based items. (i.e., items having an historical or predicted demand of one or more units in 90 days for aircraft and equipments supported):

(1) The range of demand based items will consist of all items meeting this qualification criteria.

(2) The depth of qualifying demand based items will be sufficient to satisfy 85% of the units requested in a 90 day period (filling of demands from onboard/on hand stocks).

(3) Allowance lists quantities will be predicted on combat flying hour utilization, rounds fired or other type rates as promulgated by CNO.

(4) Rotatable pool items are those repairable items required to be available for immediate installation in an aircraft or its associated equipment while the failed units are being repaired locally by the AIMD (Aircraft Intermediate Maintenance Department) or IMA (Intermediate Maintenance Activity) based upon individual site capability. Items will qualify as rotatable pool items when there is a predicted demand of one or more in 30 days. Rotatable pool quantities,as well as appropriate attrition stocks,will be included in the AVCAL.

b. Low-demand items. Items having an historical or predicted demand of less than one unit in 90 days for aircraft and equipments supported.

(1) The range of low-demand items will consist of those which qualify under the following restrictions:

(a) Items with a unit cost of $5,000 or more will be stocked if the predicted demand is equal to,or greater than,one in a six-month period.

(b) Items with a unit cost of less than $5,000 will be stocked if the predicted demand is equal to,or greater than,one in a nine-month period.

(2) Low-demand items qualifying for stockage under paragraph 4b(1) above will be included in the AVCAL in minimum depth (i.e., quantities of one or minimum replacement unit).

c. Ground Support Equipment (GSE)

(1) Repair part support of GSE does not necessarily relate directly to flying hours of aircraft support with GSE usually installed singly or in low populations. With the advent of more complex and versatile avionics and electronic GSE, these equipments will service multiple weapons systems and are essential in maintaining the readiness

of assigned aircraft. Therefore, it is necessary to prescribe a support policy which varies to some degree from that prescribed for airborne equipment. At the same time, the support of these equipments is incorporated into an integrated allowance document which can be logically developed and understood by fleet units and MAGs receiving the allowance lists. To meet these objectives, the following guidance for the determination of initial requirements is furnished:

(a) Because of the low population (equipment operating months), many times only one equipment per site, the allowance support policy for GSE will sustain a maintenance plan developed by NAVAIR or program managers which emphasizes minimum downtime. This normally will mean immediate removal and replacement of major repairable components (equivalent to airborne Weapon Replaceable Assemblies (WRAs)),and then repair of WRAs through the use of Shop Replaceable Assemblies (SRAs) and consumables at depot or intermediate level as capabilities are certified.

(b) WRAs, SRAs, and consumables will be assigned Source, Maintenance and Recoverability (SM&R) codes and Military Essentiality Codes (MECs) by NAVAIR or Program Managers, at the time of provisioning, consistent with the maintenance capabilities of IMAs and depots. IOLs are developed to provide repair part support for an initial 90 day period. In selecting the range of candidates from assigned maintenance codes applicable at the organization and IMA level, the IOL will include items which have a forecast usage of one or more in 90 days. This usage will be determined utilizing population of item and maintenance replacement factor. Replacement factors will utilize 3M data if available.

(c) There will be a number of items which do not qualify for inclusion in IOLs under the criteria in the above paragraph. NAVAIR or Program Managers will assign MECs to items selected for maintenance support,along with SM&R codes. All items not qualifying for support under paragraph 5a(2), above, but which are coded as essential and have proper maintenance codes,will be candidates for allowance lists. These low demand items will be included in the IOLs in minimum quantities if they pass the following inclusion criteria: Population times maintenance replacement factor (utilizing 3M data as available) equals an annual forecasted usage of .25 or greater (predicted or reported usage of one in 4 years).

(d) Any items, other than those qualifying under paragraphs 4c(1)(b) and 4c(1)(c), to be included in the allowance lists must satisfy the criteria and rules of TORs as set forth by Chief of Naval Material.

(e) Items considered essential to the operation of the equipment which are excluded from IOLs by the criteria above may be supported as supply system insurance items in a minimum quantity to satisfy emergency requirements.

d. Materiel Availability (effectiveness) goals:

(1) For aviation ships and MAGs, the objective for overall AVCAL performance is to fill 75% of all demands and to provide overall availability of 85% for items stocked. Issues from rotatable pools will be included in effectiveness computations. For non-aviation ships without intermediate maintenance capability, the objective is to fill 65% of all demands and to provide overall availability of 85% for items stocked.

(2) For shore activities supporting aircraft the objective for overall AVCAL performance is to fill 65% of all demands and to provide overall availability of 85% for items stocked. Issues from rotatable pools will be included in effectiveness computations.

e. Identification of overrides. Items which are included in allowance lists which qualified on other than rules cited above will be coded and identified in IM files for periodic review of original decision.

f. Depth of Stocks

(1) Rotatable pool stock levels will be based upon frequency of repair and actual turn around time, which in the majority of cases should not exceed 3 days. In any event individual item levels will be constrained to a quantity representing a maximum of 20 days turn around time.

(2) Authorized stock levels for repairable items at operating sites will be 90 days for afloat units and MAGs, 30 days for CONUS activities and 60 days for overseas activities. Afloat and overseas computations will be based on combat flying hours. Replenishment will be on a one for one basis with no additional depth authorized for order and ship time. CHNAVMAT will publish procedures for changing allowances. When promulgated, allowances will be

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regarded as maximum levels to be maintained. No retention levels will be permitted above authorized levels. Changes to authorized stock levels will be subject to inventory manager approval except where modified by subsequently approved intensive inventory management programs.

(3) Stockage objectives for expense/consumable type items will not exceed 90 days for afloat units and MAGs (based on combat rates), or ashore (based on peacetime rates), unless the Fleet CINC authorizes endurance loading for a specified ship deployment. OST will be restricted to actual or UMMIPS timeframes, whichever is lower.

(4) When interim changes are made to site loads, additional stocking will be restricted to those items not previously carried that provide increased range. Depth of currently carried items will not be increased automatically, but should be increased only when actual demand experience justifies an increase.

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IDENTIFICATION OF ACRONYMS

1. Acronyms that appear throughout the basic instruction and enclosures are identified as follows:

AEL	-	Allowance Equipage List or Average Endurance Level
AIMD	-	Aircraft Intermediate Maintenance Department
APA	-	Appropriation Purchases Account
APL	-	Allowance Parts List
AVCAL	-	Aviation Consolidated Allowance List
CINC	-	Commander In Chief
COD	-	Carrier Onboard Delivery
COSAL	-	Coordinated Shipboard Allowance List
FBM	-	Fleet Ballistic Missile
FILL	-	Fleet Issue Load List
FMF	-	Fleet Marine Force
FPSM	-	Fleet Program Support Materiel
GSE	-	Ground Support Equipment
IM	-	Inventory Manager
IMA	-	Intermediate Maintenance Activity
IOL	-	Initial Outfitting List
LAMPS	-	Light Airborne Multi-purpose System
LANTFILL	-	Atlantic Fleet Issue Load List
MAG	-	Marine Aircraft Group
MEC	-	Military Essentiality Code
MLSF	-	Mobile Logistic Support Force
MSP	-	Maintenance Support Package
NSA	-	Navy Stock Account
NSMP	-	Navy Support Mobilization Plan
OL	-	Operating Level
OST	-	Order and Shipping Time
PACFILL	-	Pacific Fleet Issue Load List
POS	-	Peacetime Operating Stock
PWRS	-	Pre-positioned War Reserve Stock
PWRR		Pre-positioned War Reserve Requirement
QAD		Quarterly Average Demand
RAV	-	Restricted Availability
RO	-	Requisitioning Objective
ROH	-	Regular Overhaul

SAMMA/SAL	-	Stores Account Materiel Management Afloat/Ship Authorized Levels
SIM	-	Selected Item Management
SL	-	Safety Level
SM&R	-	Source, Maintenance and Recoverability
SO	-	Stockage Objective
SOAP	-	Supply Operations Assistance Program
SOAP-A	-	Supply Operations Assistance Program - Aviation
SRA	-	Shop Replaceable Assembly
TARSLL	-	Tender and Repair Ship Load List
TIR	-	Transaction Item Reporting
TOR	-	Technical Override Requirement
UMMIPS	-	Uniform Materiel Movement and Issue Priority System
WRA	-	Weapon Replaceable Assembly
WSPD	-	Weapons System Planning Data

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AD 768187

RESEARCH REPORT

AN EVALUATION OF A SPARING TECHNIQUE TO DETERMINE ITS APPLICABILITY FOR GENERAL USE

by

Ronald Dean Oglesby

Accomplished as Part of the
AMC Maintainability Engineering Graduate Program
USAMC Intern Training Center

and

Presented in Partial Fulfillment of the Requirements of the
Degree of Master of Engineering
Texas A&M University
March, 1972

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ABSTRACT

Research Performed by Ronald D. Oglesby

Under the Supervision of Dr. R.J. McNichols

H.E. Lynch, R.S. Morris, Dr. R.J. McNichols, and Dr. D. R. Shreve have developed a prediction technique for the number of spares for a system, utilizing a prechosen probability level that sufficient spares would be available. The purpose of this paper is to test their technique.

The testing of the prediction technique was done by using computer simulations. Basic systems were used with different probability density functions of time to failure used for the distribution of the processes in the systems. The same basic systems were used with the prediction technique to give results that could be compared.

The results of this work showed that the prediction technique could be used in several cases to give estimates of the number of spares. In other cases the paper shows the variation between the prediction technique and the simulation. The use of the prediction technique depends upon the system and the probability density functions of time to failure.

ACKNOWLEDGMENTS

Gratitude is extended to Mr. H.E. Lynch who aided in the preparation of areas of study that were developed in this paper.

The author wishes to extend his appreciation to his committee chairman, Dr. R.J. McNichols, for his guidance and invaluable advice throughout this research project. He also wishes to thank Dr. D.R. Shreve and Dr. R.L. Street for their assistance and for consenting to be committee members.

The author also wishes to extend his sincerest appreciation to his wife, Linda, for her typing and outstanding good nature throughout his intern training program.

During the course of this work, the author was employed by the U.S. Army as a career intern in the AMC Maintainability Engineering Graduate Program. He is grateful to the U.S. Army for the opportunity to participate in this program.

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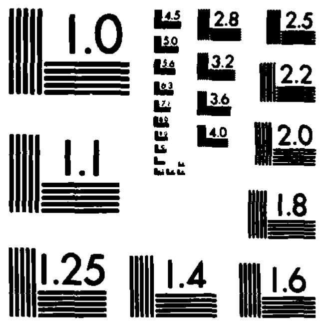

MICROCOPY RESOLUTION TEST CHART
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CHAPTER I

INTRODUCTION

In a system's lifetime the support elements perform a vital function toward the effectiveness of the system. The support elements affect the developmental time, operational readiness, and user's cost. These support elements must be taken into account at the very beginning of the system's lifetime, during the conceptual stage of the project (10)*. If they are not and the support elements are designed after the system has been developed, then this could alter all of the system parameters such as reliability, maintainability, and availability.

Importance of Spares

One of the major elements of the support concept is that of spares. The questions that need to be answered are how many spares will have to be stocked in order to meet a desired probability level that enough spares are available, and how many spares need to be stocked to assure that a minimum of system downtime will occur?

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*Numbers in parentheses refer to numbered references in the List of References.

The importance of the correct number of spares cannot be overestimated. The number of spares on hand is critical in determining whether system specifications are met. In the conceptual, definition, and developmental stages of a product's lifetime, tradeoffs are performed among the various parameters, and the number of spares affects these tradeoffs and is affected by them.

An effective and economical logistic system cannot be prepared without a good prediction of the number of spares. The logistician is working under a hardship in the beginning because no forecast can be perfect, but the degree to which predictions can be made to approximate the real situation determines how close he can come to making his part of the system function better. If too many spares are produced and they are never used then system cost rises. If, on the other hand, not enough spares are produced, then excessive downtime could cost more than the savings on the spares and, in some cases, the cost could be in the form of human lives.

Present Methods Of Predicting Spares

The prediction of the number of spares to meet a desired availability level has been developed in a variety of methods, but these methods can be broken down into two categories:

1) Methods which make assumptions which limit the range and applicability of the technique.

2) Computer simulations, which can be simple or complex depending on the model.

In the first category many intricate methods have been developed to predict the number of spares. These involve using everything related to a system from the cost of spares to the number of systems used. This category can best be thought of in a simple manner. If a system is assumed to fail and is immediately repaired, then the number of spares needed would be equal to the number of failures. Thus if a certain number of parts, M, in a system were under consideration and each part could or could not have been required to operate the entire length of time that the system was under consideration, then the i^{th} part could fail $N_i(t_i)$ times during time t_i. Then the minimum number of spares, SP, or parts that would be required to operate the system at a certain probability level, P(SP), would be:

$$P(N_1(t_1) + \dots + N_M(t_M) \leq SP) = P(SP). \qquad 1.1$$

G.H. Ebel and A.J. Lang developed a technique using this expression but they assumed:

1) a constant failure rate for their system,

2) all the parts in operation ran for the same length of time, and

3) those parts used were stochastically independent (4).

Thus their model requires that the failure rate is that of an exponential distribution. The standard deviation of the

process is then just the mean. This limits the type of system for which the model can predict the number of spares.

A.E. Holmes and W.S. McQuay have worked out a prediction technique for small numbers of parts to be spared (6). They have used the binomial distribution, but this still requires a constant failure rate for the system to be predicted. This technique also requires that all of the parts for which spares are provided must operate for the same length of time.

These two prediction techniques have been used and the results for systems that satisfy the assumptions have shown very good results.

Another procedure is to spare for the average number of failures expected to occur. This can be done by taking the mean life of the part and dividing it into the time that is desired for the part to operate. This number could then be rounded down to the nearest integer value. The value would then be the number of spares needed. This method will then stand an approximate fifty per cent chance of having the correct number of spares (8).

The second category is that of computer simulations. The computer simulation is just what it seems - a simulation using input variables, a computer program, and results from these inputs. Thus the computer must be programmed for the simulation. If the designer is not a programmer, he must convey to the programmer his ideas of how the system will work and try to get a simulation. With the complexity

of variables that go into a program this can easily be seen not to be a simple approach to the problem. The basic need for this approach is computer time. Computer time costs money which can be a major drawback if a simulation is required each time the system is changed.

Thus there has never been a simple, convenient model that covered a wide range of systems for the designer and others to work with in the prediction of the number of spares required for the system.

New Method Of Predicting Spares

H.E. Lynch, R.S. Morris, Dr. R.J. McNichols, and Dr. D. R. Shreve have developed a simple and straightforward prediction technique(8). The technique has been written in a step by step pattern so that a person without any statistical background could use it by simply following the procedure.

The technique was derived using as its basis the central limit theorem. This was done by assuming that the density function of a sum of independent random variables would approximate the normal density function as the number of random variables and time increases. This approximation should hold regardless of the type of probability density function of time to failure from which the random variables came.

During the preliminary work in the development of the

technique, comparisons were made with predicted values of spares and with computer simulations using the normal distribution of time to failure. These results were found to agree. The technique has not been tested against other probability density functions of time to failure to see if the technique will give desirable results. If the technique can be proven valid for different probability density functions of time to failure, then the designer will have a powerful tool to work with due to the simplicity of the technique and the wide range of systems it will cover.

The sparing technique under study is developed in Chapter II. The assumptions that are required for the sparing technique and the step by step procedure associated with it are stated, and an example of the calculations is also given. The test procedure and the different types of systems that were tested are stated in Chapter III. Chapter IV describes the computer programs used in the theoretical calculation and the simulations. The simulation and sparing technique results are compared in Chapter V. Conclusions are drawn in Chapter VI.

CHAPTER II

SPARING TECHNIQUE

Procedure For Using the Technique

The sparing technique must not be taken for a universal solution to all sparing problems. In order to use the technique the following conditions must be met(8):

1) The system must follow the process sequence in Figure 2.1 and one of the sparing configurations of Table 2.1.

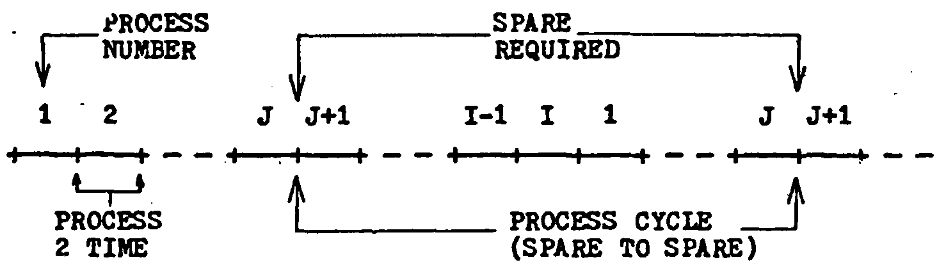

FIGURE 2.1 PROCESS SEQUENCE

2) Only one spare set can be required in any process cycle, where a process cycle is defined as the repeating sequence in a system, and it must be required at the point in time shown in the process sequence.

3) All processes are independent.

4) The mean and variance of the density function of each process must remain constant over time.

To use the technique certain variables must be known. The number of systems, S, and the time, T_i, that each of

I. SINGLE SYSTEM S=1
SPARING CYCLE $=T_1$

II. MULTIPLE SYSTEMS - EACH SEQUENCE IS IDENTICAL.
NUMBER OF SYSTEMS = S
SPARING CYCLES OF ALL SYSTEMS ARE EQUAL TO T_1.

III. MULTIPLE SYSTEMS - EACH SYSTEM SEQUENCE IS IDENTICAL.
NUMBER OF SYSTEMS = S
SPARING CYCLE OF EACH SYSTEM $= T_R$ AND MAY BE DIFFERENT.

NOTE: THE SYSTEM CONFIGURATION IDENTIFIES HOW MANY SYSTEMS, S, WILL RECEIVE SPARES FROM THE SPARE POOL AND THE LENGTH OF TIME, T_R, EACH SYSTEM WILL BE IN THE PROCESS SEQUENCE DURING THE SPARING CYCLE.

TABLE 2.1 SPARING CONFIGURATION TYPE

systems is to be required to operate must be known. The sequence of processes that a system undergoes must be determined. The number, I, of these processes can be related to Figure 2.1 to correctly identify the proper sequence of events. The position or process, J, where the spare will be required in the process cycle must be correctly identified. The different process means, u_i, variances, σ_i^2, and the third moment, $MC3_i$, of the process cycle time density function about its mean must be known. The desired probability level, P, that sufficient spares will be available should be determined.

The technique then follows a set of steps to calculate the desired number of spares. Several basic functions must first be calculated:

$$T=\sum_{i=1}^{S} T_i + S\sum_{i=J+1}^{I} u_i, \qquad 2.1$$

$$u_c=\sum_{i=1}^{I} u_i, \qquad 2.2$$

$$\sigma c^2=\sum_{i=1}^{I} \sigma_i^2, \qquad 2.3$$

$$K1=(u_c^2 - \sigma_c^2)/(2u_c^2), \qquad 2.4$$

and

$$K2= 1/12 + 5\sigma_c^4/(4u_c^4) - 2\sum_{i=1}^{I} MC3/(3u_c^3). \qquad 2.5$$

The predicted mean and variance of the sparing configuration can now be determined. The mean value can be calculated by;

$$u_s = T/u_c - SK1, \qquad 2.6$$

and the variance by;

$$v_s = T\sigma_c^2 / u_c^3 + SK2. \qquad 2.7$$

Now the probability level that was given is used to determine a value, Z, from standardized normal tables. The value is used with the values u_s and v_s to give the first estimate of the number of spares,

$$N = u_s + Z\sqrt{v_s} . \qquad 2.8$$

This gives a starting point in the iteration to find the predicted number of spares. This value is rounded upward to the nearest integer value, N'. This value is then used to calculate:

$$u_p = (N'+1)u_c - S\sum_{i=J+1}^{I} u_i, \qquad 2.9$$

$$\sigma_p^2 = (N'+1)\sigma_c^2 - S\sum_{i=J+1}^{I} \sigma_i^2, \qquad 2.10$$

and

$$u_p' = u_p + (S-1)u_c K1. \qquad 2.11$$

A normalized value, Z', can then be found as

$$Z' = (u_p' - \sum_{i=1}^{S} T_i)/\sigma_p. \qquad 2.12$$

This value can then be looked up in the standardized normal tables and a probability level that sufficient spares will be available can be found. This value can then be compared against the desired probability level. If the value is too high then a new value can be found by decreasing the number of spares, N', by one and repeating the process starting with Equation 2.9. This can be repeated until the least number of spares that will give either the desired probability or one slightly higher than the desired probability can be found. If, on the other hand, a probability is found less than the desired probability, add one to the number, N', and repeat the sequence starting with Equation 2.9.

Example

An example of the technique will now be presented to illustrate the calculations. The number of systems used will be three processes per system. Since all of the systems are identical only one of the systems is illustrated in Figure 2.2. From this it is seen that the spare is required at the end of the first process. Each of the three systems will be required to be in use 310 time units. The desired probability level that sufficient spares will be available is .92.

The thre- processes will be taken as exponentials with $u_1 = 40$, $\sigma_1^2=1600$, $u_2=10$, $\sigma_2^2=100$, $u_3=12$, and $\sigma_3^2=144$. The third moment of the exponential about the mean is defined as two times the cubed value of the mean.

FIGURE 2.2 EXAMPLE PROCESS SEQUENCE

With this it is now a simple task to start with Equation 2.1 and calculate the desired values. The basic parameters are $T=996$, $u_c=62$, $\sigma_c^2=1844$, $K1=.26014$, and $K2=.00232$.

The desired probability level is .92 and this value can be found in a standardized normal table to give $Z=1.41$. Now by using Equation 2.8 the first estimate of the number of spares can be calculated as $N=19.19$. The first estimate of the number of spares would be $N'=20$.

The basic parameters have now been calculated. The probability that sufficient spares will be available can now be calculated by using an estimate of 20 spares. Starting with Equation 2.9 the parameters are $u_p=123.6$, $\sigma_p^2=37992.0$, and $u_p'=1268.26$. Equation 2.12 gives a Z' value of 1.453. This value can be found in a standardized normal table to give a probability level of .958 for 20 spares.

The desired level was .92; thus 20 spares could be too

many. The next step would be to decrease the spares to 19 and go back to Equation 2.9. This gives new values of u_p=1174.0, σ_p^2=36148.0, u_p'=1206.25, and Z=1.453. This value then gives a desired probability level of .926 for 19 spares.

The desired level is still .92. As can be seen there could still be too many spares to give the desired results. The next step would be to reduce the number of spares to 18 and start with Equation 2.9 again. A probability level of .876 would be found. This is less than the desired level of .92. Thus the correct solution would be to use 19 spares and have a probability level of .926 that enough spares would be available.

The technique has been derived and the approximations used have theoretical background as to their validity. Computer simulations have been run using the normal density function of time to failure in an attempt to justify the method. These simulations were not run for a large number of cases; thus there was not adequate information to support the theory. The technique has not been tested using various other probability density functions of time to failure and the range of the variation of the process parameters has not been studied.

Thus it is the purpose of this paper to find the region of feasibility for the prediction technique by using different probability density functions of time to failure through computer simulations and theoretical comparisons.

Chapter III will describe the areas that are to be studied. The method of examining thes; separate areas will als: be presented.

CHAPTER III

TEST PROCEDURE

It was decided to use as general a configuration as possible during the initial development of the test procedure. This configuration would be three systems, with each system being composed of three processes. These processes of operation, repair, and test were described in the previous example. This configuration would be used in the computer simulation to give a simulated number of spares and the corresponding proportion of the total number of spares. A corresponding time would be associated with the simulation. The prediction technique would also be used with this configuration to give sparing levels and corresponding probability levels for the same operating time. The processes in the simulation and the prediction technique will have the same mean values and variances.

The testing will consist of running a simulation for one point in time or a desired time period for the systems to operate. The means of the processes are required knowledge. Therefore the time increments that will be run will be multiples of the means of one sparing cycle. These tests will be run from one and up to at least eight multiples of the sparing cycle mean. This should cover a wide range of situations.

Several areas of further research of the prediction technique were presented in the paper prepared by H.E. Lynch, R.S. Morris, Dr. R.J. McNichols, and Dr. D.R. Shreve(8). One of these areas was to study different coefficients of variation (standard deviation/mean) of the process density function.

There are three areas that should be considered in order to study the coefficient of variation. The first area is when the coefficient is greater than one and the process density function of time to failure is skewed left. This can be accomplished by using the Weibull density function for the probability density function of time to failure. The skewness can be caused by having a decreasing failure rate. Since the Weibull distribution is defined by three parameters, the mean value, standard deviation, and the location parameter can be set, and thus define the system.

The coefficient of variation can be set equal to one. This would mean that the mean value and standard deviation of each process would be the same value. Therefore the process density function would be that of the exponential distribution. This system will be created in two different methods. One method will be to set the first process density function equal to the exponential. The mean will be equal to the sum of the means used in the process making up the system in the sparing technique. The remaining processes in the simulation will have zero means and variances.

In other words, the system will be composed of one process with the exponential distribution of time to failure. The second method will be to use exponentials for each of the separate processes in the simulation and use the correspon- ding values in the sparing technique.

The third method will be to have the coefficient of variation less than one, and the process density function skewed right. This method will also utilize the Weibull density function of time to failure. This can be done by making the process density function have an increasing failure rate.

These simulations will be run for a point in time to get the number of spares until a point is reached where a running mean of the number of spares will be found not to change significantly. In order to achieve a random simulation a minimum number of simulations will have to be run so that enough variations will be entered into the calculations. A maximum number of simulations must be found in case the pro- cess mean and variance do not reach a constant value. This must be done so that the computer will not continue to run and possibly go into an endless loop.

The mean and variance of the number of spares for the prediction technique and simulation process will be found for each point in time. Before they can be compared, the distribution of the spares for the simulation will be checked to see if it approximates a normal distribution by a test

such as the Chi-Squared test for goodness of fit. If the hypothesis that the distribution of spares is normal is accepted at a certain significant level, the means and variances can be compared at that point in time. The number of spares can also be compared for a certain confidence level and the confidence levels for a certain number of spares can also be compared. If the hypothesis is rejected, then the sparing level can be found from the total number of spares by using the confidence level for the prediction technique and these levels can be compared to the predicted number of spares. The predicted number of spares can also be taken and the corresponding confidence level for that number of spares could be found from the sparing density function.

The sparing technique is based upon the normal distribution. To test the sparing technique, simulations will be run using the normal density function of time to failure for each process density function. This testing would be done by using two separate methods. The values of the process means and variances for the case where the coefficient of variation was greater than one would give a comparison of the simulated value and the theoretical value. These values could then be compared against those that were used with the Weibull density function. The same results can then be found using the case where the coefficient of variation is less than one.

Another area of interest is where the process densities are skewed left and right. This can be accomplished by making the first process density function a Weibull with a decreasing failure rate, the middle process density function is normal, and the last process density function a Weibull with an increasing failure rate. This configuration would be run at different points in time checking the number of spares at each point in time to see if the sparing function is approximating a normal distribution. The number of spares for the desired confidence level will be compared with the predicted number of spares for the same confidence level. Conclusions should be drawn from the number of spares and those simulated for a confidence level and the variation of confidence levels for a specific number of spares.

The sparing technique has a special feature that will be tested. Table 2.1 shows a third case which is unique. This case shows that for multiple systems the desired time of operation does not have to be equal. In Chapter I the technique by A.E. Holmes and W.S. McQuay (6) and the technique by G.H. Ebel and A.J. Lang (4) were both based upon the principle that the desired time of operation of the systems were all the same. Thus the sparing technique has a useful application that must be tested. This will be accomplished by having one of the three basic systems run for a longer time increment than the other systems.

The following chapter will describe the development of the computer program for the simulation and the computer program of the sparing technique.

CHAPTER IV

COMPUTER PROGRAMS

Computer Program Development of Sparing Technique

A computer program was developed utilizing the theoretical calculations in Chapter II. This program was written to be as general as possible. It was developed in this manner so that different process density functions of time to failure could just be inserted in the program at the proper points. The body of the program is shown in Appendix I.

The initial conditions or variables must first be chosen. These include the number of systems, number of processes, process where the spare is required, the time each system is required to operate, and the desired probability that sufficient spares will be available. The different process means and variances must be known. The density functions of the processes must be selected so that calculations of the third moment about the mean of each process can be found. These moments are then summed to give the third moment about the mean for the process cycle. These initial conditions make no restrictions as long as they meet those imposed in the conditions in Chapter II. In other words, as long as the conditions are met, the theoretical calculations are the same.

The program was developed so that it could be compared

against the results of a computer simulation. Equations 2.1 through 2.7 show that during the initial calculations the desired probability level of sufficient spares is not required. This is unique in the sense that for a desired time period the theoretical mean and variance of the sparing distribution are easily obtainable without using the probability level.

The first estimate of the number of spares for a desired availability level is now ready. It was desired not to have just one estimate of the number of spares for a desired availability level but to have the desired availability level run from 50 per cent probability of sufficient spares to approximately 100 per cent. This was desired so that the results could be compared with those of the corresponding simulation. Therefore for the first estimate of spares a desired probability level of 99.99 per cent was chosen. Figure I.1 shows the routine of using Equations 2.9 through 2.12. This would proceed to give a predicted number of spares and the corresponding predicted probability level. After this was done the number of spares would be decreased by one and the process would be repeated.

This procedure would continue until the value Z' in Equation 2.12 reaches a negative value. This was done for two reasons. The first reason is Z' decreases to zero and the corresponding probability level associated with the value of zero is 50 per cent. There are very few systems

that will be desired with a probability of less than this amount. Also, if a level less than this amount is desired, then it would be just as easy to spare for the mean life. The second reason is that the calculations were stopped at this point due to the theoretical equations themselves. Equation 2.9 calculates a value u_p which is made up of two parts:

1) $(N'+1)u_c$

2) $S\sum_{i=j+1}^{I} u_i$.

These two parts are capable of becoming negative value when part 2 is subtracted from part 1, if the value N' is small. This value affects Equation 2.11 when this negative value is larger than $(S-1)u_cK1$. Equation 2.10 is also capable of becoming a negative value. This term is defined as a squared term. If it proceeds to a negative value then the square root of the term would be an imaginary term.

Thus this program is capable of performing the theoretical calculations and giving results for a sparing level and the corresponding probability level. This probability level is in the range from 50 per cent to 100 per cent and these results can be compared against the computer simulation.

Computer Simulation of Sparing Problem

The computer program for the simulation routine was also written to be as general as possible. This was done so that to change the probability density functions of the various processes would only require changing the input variables. The computer program is shown in Appendix II.

In the simulation the first item performed was that an array of integer values was read into the program. The reason for this was due to an IBM system supplied routine to give a uniform randon variable which was used in the program. Its use will be explained further in this section. The type of system that was designed to be simulated would have to be selected. This involves putting in the number of systems, the number of processes, the process in which a spare would be required, and the means and variances of each process. The process density function of time to failure would have to be selected. The equations for each process density function would be rearranged so that when a probability of failure is given the corresponding time to that failure can be calculated. Then the initial time period that each of the systems was required to operate is set. This is done so that after the simulation is run for that period, the time could be incremented and the simulation could then be run for a new time period.

The computer system that the simulation was to utilize

was an IBM 1130. This computer was very adequate for the simulation except that it was slow and had a limited core size. Due to this limited core size it was decided that the program would run for a maximum of six hundred simulations for one time period.

A scientific subroutine supplied by IBM was used in the system to give a uniform distributed random variable. This random variable is supplied as a percentage point between zero and one. In order to use this subroutine an integer seed value has to be supplied. This seed value gives better results as if it is a prime value. It was desired to keep the simulation as random as possible. These seed values were found to repeat themselves after the subroutine was repeatedly called several times.

It was then possible that a simulation could be run with an initial seed value and then this value could come up again. This did not affect the results unless this seed value turned up again at the beginning of a new iteration. Thus the values that would follow would just be repeated values. Therefore the simulation would not be random. A method was devised to get around this. All of the initial seed values were put in an array. Then when a new iteration was started the new seed value was compared against all of the previous seed values that were used to start simulations for that time period. If this value was different from all

of the others a new iteration was started. If the value had been used previously then one of the values that had been read in was used and then it was checked to see if it had been used. This continued so that all of the iterations within a simulation would be different.

The initial seed values that were read into the computer program were found by the author. These values were found by using a computer program to find all of the prime numbers from 13597 to 32749. These prime numbers were set up in an array of six pages, six columns, and six rows of ten numbers. In order to get a random array of 50 values out of these numbers the author used three dice to determine the page, the column, and the row. Then a random number table was used to obtain values from zero to nine. This method was employed until the fifty values had been determined.

Each of the systems defined in the input variables were simulated independently. The program does this by simulating spares for one system at a time. At this point the program used the random number generating subroutine. Then, depending upon the initial system configuration as to whether the different processes were normal, Weibull, or exponential, the random probability was used to calculate a corresponding time increment for that process. This time increment was added to the time that the system had already accumulated. The total time would then be checked against the desired time period of operation for that system.

If this time was less than the desired time of use then the process was checked. If the process was where a spare was required, then a spare was added to the total number of spares for that simulation. The program would then simulate a time for the next process. If the process did not require a spare, then the program would go on and simulate a time for the next process.

This process was continued until the simulation time of the system was larger than the desired time of system use. The program was then repeated for the next system until all of the systems had been accounted for. One simulation had been done after enough spares were found to keep all of the systems in operation for their desired time periods.

As had been previously stated the program was supposed to run for six hundred simulations to get a representative simulation. As the simulations were performed a running mean and standard deviation of the spares was calculated. As the number of simulations increased the variation of the sample mean value became less and less. This trend was expected, so after 100 simulations, the program began to check the change in the mean value from one simulation to the next. If the variation in the mean was less than .0005 for ten simulations then the procedure stopped simulating new values. The value .0005 was chosen because it represented a small change in the mean values. The reason that the change must

hold for ten occurences was to eliminate the possibility that the change was not due to chance occurences.

After the program had been run and the difference in means was within the limits the required number of times, it left the simulation loop. The numbers of spares in the array were the results of a random simulation but they were all whole numbers since a fraction of a spare was not practical. These spares were divided up into a frequency array so that the number of times each spare was used could be tabulated. This array was printed in a histogram to give a pictorial representation of the spares distribution.

Once the frequency distribution had been set up, a Chi-Squared goodness of fit test was run on the spare set. This test was run to compare the frequency distribution of the spare set with a theoretical normal distribution having the same total number of simulations, the same mean, and the same standard deviation. The procedure used in this test was taken from Quality Control and Industrial Statistics (3).

The degrees of freedom for the test corresponded to the number of cells that were used in the calculations. This value had to be altered. This was due to the fact that three degrees of freedom were lost due to the fitting process. These three degrees of freedom corresponded to the fact that the total number of simulations, the mean, and standard deviation of the spare set were used. Thus the actual degrees of freedom for the Chi-Squared value were the number of cells minus three (3).

This simulation program was used for the different types of systems configurations that were described in Chapter III. The theoretical program was used with the same configuration. The results of these are presented in Chapter V.

CHAPTER V

RESULTS

This chapter deals with the results obtained from the computer simulations and the sparing technique. Chapter III described the different types of systems that were tested. The results of the test sequence will be given in this chapter.

With the exception of one test, all of the test systems were composed of three processes each. The mean value of the processes, u, was set at initial values and remained the same for the different types of probability density functions that were used. The variance, σ^2, of each process was changed to meet the requirements that were imposed by the test.

There will be two tables of results included in this chapter for each case. The first table will give the process parameters used in the test. These will be the mean, variance, and coefficient of variation. If other parameters such as those that were used in the process utilizing the Weibull density function were required, then they are given. This table will have the desired time of operation and the corresponding values of the mean and standard deviation from the simulation and prediction technique.

The number of iterations of the simulation for the corresponding time period is given. The degrees of freedom

that were found from the Chi-Squared goodness of fit test are given. The Chi-Squared value from each simulation is also given. The degrees of freedom and the Chi-Squared values found in the test were used in conjunction with a Chi-Squared table to obtain the α level(3).

This table also shows the relationship of the predicted mean value, u_p, with the simulated mean value, u_s. This was done by dividing the predicted mean value by the simulated mean value. This same procedure was also used for the standard deviations of the sparing technique, σ_p, and the simulation, σ_s.

The second table occupies more than one page. This is due to the large number of values that were tabulated. The actual results of the simulation and the prediction technique are presented in this table for each time period. The time periods listed in this table are set up in multiples of the sparing cycle mean life. Since the mean life is 50, the time periods are 50, 100, and so forth. These time periods consist of all the time from zero to the va[illegible] listed. For one time period a spare level is shown and the co[illegible]sponding probability level that sufficient spares are available from both the prediction technique and the simulation.

In the simulation previously mentioned a Chi-Squared goodness of fit test was used. In order to perform this test the upper and lower cells of the spare array had to be added. The spare level is marked for each time period at

the point where the remainder of the spare levels had to be added.

Coefficient of Variation Greater Than One

The first area of interest was concerned with the coefficient of variation of the process being greater than one and the process density function skewed left. The probability density function of time to failure was the Weibull,

$$f(t,A,B,G)=(B/A)\ (t-G)^{B-1}e^{-(t-G)^{B/A}}. \qquad 5.1$$

The Weibull is defined by three parameters. The location parameter, G, for this system was set equal to zero. The value of time, t, could then be varied from zero. The value could be varied to any value desired. The values of the shape parameters, B, and the scale parameters, A, were then left. These two parameters could then be made dependent upon the mean and variance.

The mean values of each process were chosen. The conditions that were defined for this test limited the range of the shape parameter. In order for the process density functions to be skewed left the shape parameter must be less than one. The shape parameter was then used with the mean value to give the scale parameter (7). The variance of each process was then a function of that process shape and scale parameter.

Two distinct cases were considered for this test. Case

A and Case B were set up to have identical parameters in the second and third processes. These parameters are presented in Tables 5.1 and 5.3. The first process had the same mean value but the shape parameter was changed so that Case A had a variance of 6124.99 and Case B had a variance of 2242.02. This created two systems where the coefficient of variation for each process was greater than one while for Case B the coefficient of variation of the sparing cycle was less than one. This can easily be seen. Case A in Table 5.1 has a sparing cycle mean of 50 and a sparing cycle variance of 6331.81. This gives a coefficient of variation of 1.59 for the sparing cycle. Case B in Table 5.3 has a sparing cycle mean of 50 and a sparing cycle variance of 2448.83. This gives Case B a coefficient of variation of .99 for its sparing cycle.

The results from Case A are presented in Tables 5.1 and 5.2. The results of the Chi-Squared goodness of fit test are shown in Table 5.1. The level varies from a value of .95 to .005. Only two time periods show levels less than .05.

Table 5.2 shows the probability levels for Case A. These results show that as the time periods became larger, the values of the sparing technique between 50 per cent and approximately 75 per cent had a marked improvement in their correlation. That is, at the time period of 50 for a 74 per cent probability of sufficient spares, the prediction

technique would require eight spares while the simulation would require only six spares. At the time period of 250 the simulation would require 21 spares while the prediction technique would require 22 spares. At 400 both the simulation and prediction techniques would require 32 spares.

For the probability levels between 75 per cent and 100 per cent a trend started to develop. The greater the probability desired the greater discrepancy between the predicted and simulation values. This can be seen by assuming a probability level of 80 per cent, at the time period 50, the simulation would require six spares while the prediction technique would require nine spares, or a difference of three spares. At the time period of 400 the simulation would require one less spare than the prediction technique. If 90 per cent were used at a time of 50, a difference of five spares would be found while at time 400 a difference of three spares would be found.

The results of Case B are presented in Table 5.3. The coefficient of variation of each process should be noted. The coefficients for the three processes are identical.

The α levels are all greater than the .05 level except for the initial time period of 50. Comparison of the ratio of the means and ratio of the standard deviation can be seen. For each time period the ratios of the means for Case B were less than the corresponding values for Case A. The same

situation held for the ratios of the standard deviations.

The probability levels and corresponding sparing levels are in Table 5.4. These results show a larger degree of correlation than do those of Case A. For probability levels from 50 per cent to 90 per cent the simulated and predicted values correspond for all of the time periods. Using a probability level of 90 per cent there was a trend difference of spares between the prediction technique and the simulation. The prediction technique was constantly giving probability levels below those of the simulation for corresponding sparing levels.

TABLE 5.1 COEFFICIENT OF VARIATION GREATER THAN ONE, CASE A

3 SYSTEMS

SPARING CYCLE: PROCESS 2(WEIBULL), PROCESS 3(WEIBULL), PROCESS 1(WEIBULL)

$u(1)=35.00$	$\sigma(1)^2=6124.99$	$B(1)=.5$	$A(1)=4.18$	$\sigma/u=2.24$
$u(2)=7.0$	$\sigma(2)^2=89.68$	$B(2)=.75$	$A(2)=3.78$	$\sigma/u=1.35$
$u(3)=8.0$	$\sigma(3)^2=117.14$	$B(3)=.75$	$A(3)=4.17$	$\sigma/u=1.35$

TIME PERIODS	PREDICTION TECHNIQUE		SIMULATION						COMPARISON	
	u_p	σ_p	u_s	σ_s	N.S.	D.F.	X^2 VALUE	α LEVEL	u_p/u_s	$\sigma_p/_s$
50	6.20	4.09	4.69	2.10	165	6	4.10	.5	1.32	1.94
100	9.19	3.02	8.37	2.96	157	9	3.06	.95	1.10	1.02
150	12.20	1.22	11.44	3.86	196	13	25.27	.025	1.07	0.32
200	15.20	2.47	14.34	4.36	140	15	8.79	.8	1.06	0.57
250	18.20	3.70	17.61	4.69	163	17	17.90	.3	1.09	0.79
300	21.20	4.61	21.08	5.81	138	20	27.26	.1	1.01	0.80
350	24.20	5.38	23.12	6.78	156	24	17.66	.8	1.05	0.80
400	27.20	6.04	26.81	7.05	148	25	45.22	.005	1.01	0.86

N.S. NUMBER OF SIMULATIONS
D.F. DEGREES OF FREEDOM
( ) PROCESS

TABLE 5.2 COEFFICIENT OF VARIATION GREATER THAN ONE, CASE A

TIME PERIODS

SPARE	50 X	50 Y	100 X	100 Y	150 X	150 Y	200 X	200 Y
5	65.5	55.8						
6	81.2	64.6						
7	92.7	71.6						
8	96.4	77.3	54.8	54.7				
9	97.6	81.9	64.3	62.2				
10	98.8	85.5	77.1	68.7				
11	99.4	88.4	85.4	74.2				
12	99.9	90.7	91.7	78.7	58.7	60.8		
13			95.5	82.5	66.3	66.7		
14			97.5	85.7	77.0	71.9	51.4	53.6
15			98.1	88.3	85.2	76.4	63.6	59.7
16			99.9	90.4	91.3	80.2	71.4	65.2
17					94.9	83.4	77.9	70.1
18					95.4	86.4	83.6	74.5
19					98.0	88.5	90.7	73.3
20							92.1	81.6
21							93.6	84.5
22							95.7	86.9
23							97.1	89.1
24							97.9	90.7
25							99.3	92.2
26							99.9	

X=SIMULATION PROBABILITY LEVEL Y=PREDICTED PROBABILITY LEVEL

TABLE 5.2 (continued) COEFFICIENT OF VARIATION GREATER THAN ONE, CASE A

TIME PERIODS

SPARE	250		300		350		400	
	X	Y	X	Y	X	Y	X	Y
18	59.5	58.9						
19	66.3	64.1						
20	71.8	68.8						
21	76.7	73.6	51.4					
22	85.3	76.7	57.2	63.1				
23	89.6	80.0	65.2	67.6	54.5			
24	93.3	82.9	70.3	71.7	59.0			
25	95.7	85.4	79.0	75.4	66.0			
26	96.3	87.6	82.6	78.6	71.8	66.7		
27	97.5	89.6	85.5	81.5	76.[illegible]	70.6		
23	98.2	91.2	89.1	84.1	80.1	74.2	57.4	
29	99.4		91.3	86.4	82.7	77.4	64.9	
30	99.4		92.8	88.3	84.0	80.3	68.2	69.7
31	99.9		95.7	90.0	86.5	82.9	73.6	73.2
32			99.3	91.6	90.4	85.2	79.1	76.4
33			99.9		92.4	87.2	84.5	79.2
34					94.2	89.6	87.8	81.8
35					94.9	90.6	90.5	84.2
36					96.1	91.9	92.6	86.2
37					98.7		94.6	88.1
38					98.7		97.3	89.7
39					98.7		98.6	91.1
40					100.0		99.3	92.3
41							99.3	
42							99.3	
43							99.3	
44							99.3	

X=SIMULATION PROBABILITY LEVEL Y=PREDICTED PROBABILITY LEVEL

TABLE 5.3 COEFFICIENT OF VARIATION GREATER THAN ONE, CASE B

3 SYSTEMS

SPARING CYCLE: PROCESS 2(WEIBULL), PROCESS 3(WEIBULL), PROCESS 1(WEIBULL)

$u(1)=35$	$\sigma(1)^2=2242.02$	$B(1)=.75$	$A(1)=12.62$	$\sigma/u=1.35$
$u(2)=7$	$\sigma(2)^2=89.68$	$B(2)=.75$	$A(2)=3.78$	$\sigma/u=1.35$
$u(3)=8$	$\sigma(3)^2=117.13$	$B(3)=.75$	$A(3)=4.17$	$\sigma/u=1.35$

TIME PERIODS	PREDICTION TECHNIQUE		SIMULATION						COMPARISON	
	u_p	σ_p	u_s	σ_s	N.S.	D.F.	X^2 VALUE	α LEVEL	u_p/u_s	σ_p/σ_s
50	3.87	1.50	3.65	1.75	198	5	20.89	.001	1.06	0.86
100	6.87	2.28	6.92	2.42	147	8	6.84	.5	0.99	0.94
150	9.87	2.85	9.75	2.89	170	9	7.59	.5	1.01	0.99
200	12.87	3.33	12.74	3.57	155	12	8.35	.7	1.01	0.93
250	15.87	3.71	15.93	3.52	135	12	15.31	.2	0.99	1.06
300	18.87	4.12	18.88	3.91	154	13	17.50	.1	1.00	1.05
350	21.87	4.46	21.71	4.17	140	14	11.77	.5	1.01	1.07
400	24.87	4.78	25.06	4.80	146	16	24.65	.05	0.99	1.00
450	27.87	5.68	27.99	4.80	156	18	17.26	.5	1.00	1.14
500	30.87	5.36	30.66	5.54	136	19	28.82	.05	1.01	1.00
550	33.87	5.63	33.67	5.21	130	17	7.97	.95	1.01	1.08

N.S. NUMBER OF SIMULATIONS
D.F. DEGREES OF FREEDOM
( ) PROCESS

TABLE 5.4 COEFFICIENT OF VARIATION GREATER THAN ONE, CASE B

SPARE LEVEL	TIME PERIODS 50		100		150		200		250		300	
	X	Y	X	Y	X	Y	X	Y	X	Y	X	Y
3	51.0	52.5										
4	72.2	69.8										
5	87.4	81.4										
6	90.9	88.7	40.1	51.8								
7	96.5	93.2	59.2	65.7								
8	99.5	95.9	74.1	76.5								
9	100.0	97.6	87.7	84.3	46.5	51.5						
10			95.2	89.7	60.0	63.5						
11			97.3	93.4	71.2	73.4						
12			97.9	95.8	85.3	81.1	45.8	51.3				
13			97.9		96.6	86.9	56.8	61.9				
14			100.0		93.5	91.1	65.8	71.1				
15					97.1	94.0	78.1	78.6				
16					98.8	96.0	87.1	84.5	59.3	60.8		
17					100.0	97.4	92.9	89.0	68.8	69.4		
18						98.3	96.1	92.9	79.3	76.6		
19							96.8	94.7	86.7	82.5	59.7	60.0
20							98.1	96.4	89.6	87.1	66.2	68.0
21							99.4	97.5	96.1	90.1	77.7	75.0
22							99.4	98.3	94.8	93.4	77.9	80.8
23							100.0		97.8	95.3	84.4	85.5
24									99.3	96.8	90.9	89.3
25									99.3	97.8	94.8	92.1
26									100.0		98.1	94.3
27											99.4	95.9
28											100.0	97.1
29												98.0

X=SIMULATION PROBABILITY LEVEL Y=PREDICTED PROBABILITY LEVEL

TABLE 5.4 (continued) COEFFICIENT OF VARIATION GREATER THAN ONE, CASE B

TIME PERIODS

SPARE LEVEL	350		400		450		500		550	
	X	Y	X	Y	X	Y	X	Y	X	Y
22	56.4	59.3								
23	68.6	66.8								
24	78.6	73.6								
25	84.9	79.4	55.5	58.8						
26	88.6	84.1	61.6	66.0						
27	91.4	87.9	71.2	72.5						
28	92.1	91.6	76.0	78.1						
29	94.9	93.3	83.6	82.8	56.4	65.2				
30	97.1	95.1	87.7	86.7	66.7	71.5				
31	98.6	96.5	91.1	89.9	74.2	77.6				
32	99.3	97.5	92.5	92.4	81.1	81.7	63.9	64.5		
33	100.0		95.2	94.3	86.5	85.6	71.3	70.6		
34			96.6	95.8	89.1	88.8	77.2	75.9		
35			98.6	96.9	94.2	91.5	79.4	80.6		
36			98.6	97.8	96.8	93.5	86.6	84.6	76.8	69.8
37					98.1	95.1	91.2	87.9	75.4	75.0
38					99.4	96.4	94.1	96.6	80.8	79.7
39					100.0	97.3	94.9	97.8	86.9	83.6
40						98.1	96.3	94.5	92.3	87.0
41							99.3	95.8	94.6	89.7
42							99.3	96.8	95.3	92.0
43							100.0	97.7	96.9	93.8
44									97.7	95.3
45									98.5	96.4
46									98.5	97.3
47									98.5	98.0

X=SIMULATION PROBABILITY LEVEL Y=PREDICTED PROBABILITY LEVEL

Coefficient of Variation Equal One

The first part of this test was designated Case C. This part used a single process for each of the three systems. The process used the exponential probability density function of time to failure. Since the other tests were using a sparing cycle mean life of 50 time units, the mean life of this process was also set at 50.

These results are given in Table 5.5. The α level for this test varied but the least it became was .05. This occured at the time period of 50 which was equal to one mean life.

The probability levels and sparing levels are given in Table 5.6. This table shows that for time periods of 50 upward to 400 that for probability levels below 80 per cent the prediction technique probability was larger than the corresponding simulated probability for a spare level. Probability levels larger than 80 per cent tended to have a smaller predicted probability than the corresponding simulation.

The second part of the test was Case D. This part used three processes for each of the three systems. Each of the process density functions of time to failure was exponential. These results are given in Table 5.7.

In this test, the α level reached its lowest value at the time period 150. This value was .025 while for other time

periods the lowest α level was .1.

Table 5.8 gives the probability levels for this test. These results show that for lower probability levels the prediction probability level was larger than the simulation for the range from 50 per cent to 80 per cent. In the 80 per cent to 90 per cent range this trend reversed and the predicted values became smaller than the corresponding simulation values.

TABLE 5.5 COEFFICIENT OF VARIATION EQUAL ONE, CASE C

SPARING CYCLE: 3 SYSTEMS
PROCESS 1(EXPONENTIAL)

$u(1)=50.0$ $\sigma(1)^2=2500.0$

TIME PERIOD	PREDICTION TECHNIQUE		SIMULATION						COMPARISON	
	u_p	σ_p	u_s	σ_s	N.S.	D.F.	χ^2 VALUE	α LEVEL	u_p/u_s	σ_p/σ_s
50	3.0	1.73	3.09	1.87	184	6	12.83	.05	0.97	0.93
100	6.0	2.45	6.07	2.63	168	8	9.27	.3	0.99	0.93
150	9.0	3.00	9.36	2.88	169	9	11.37	.2	0.96	1.04
200	12.0	3.46	11.78	3.07	145	10	7.38	.5	1.02	1.13
250	15.0	3.87	15.14	4.06	153	14	10.66	.7	0.99	0.95
300	18.0	4.24	18.05	4.35	133	14	14.77	.3	0.99	0.98
350	21.0	4.58	20.72	4.16	149	14	17.09	.2	1.01	1.10
400	24.0	4.90	24.69	4.73	134	16	14.00	.5	0.97	1.04
450	27.0	5.20	27.27	5.13	173	18	17.31	.5	0.99	1.01
500	30.0	5.48	29.84	5.46	135	18	18.47	.3	1.01	1.00
550	33.0	5.74	32.50	5.08	130	17	21.43	.2	1.02	1.13
600	36.0	6.00	35.71	6.24	143	22	18.81	.5	1.01	0.96

N.S. NUMBER OF SIMULATIONS
D.F. DEGREES OF FREEDOM
( ) PROCESS

TABLE 5.6 COEFFICIENT OF VARIATION EQUAL ONE, CASE C

TIME PERIODS

SPARE LEVEL	50		100		150		200		250		300	
	X	Y	X	Y	X	Y	X	Y	X	Y	X	Y
3	59.8	69.1										
4	76.6	81.4										
5	90.8	89.6										
6	95.7	93.5	57.1	64.7								
7	97.8	96.1	67.3	76.0								
8	99.5	97.7	86.4	84.1								
9	100.0	98.1	90.5	89.7	55.03	62.4						
10		99.2	96.4	93.4	67.5	72.7						
11			97.6	95.8	76.9	80.7						
12			99.4	97.4	86.9	86.6	58.6	60.9				
13			100.0	98.4	91.1	96.9	72.4	70.4				
14				99.0	94.7	93.9	82.1	78.1				
15				99.4	97.6	96.0	86.9	84.1				
16				99.6	99.4	97.4	93.1	88.7	61.4	68.6		
17					99.4	98.3	97.2	92.1	73.8	76.0		50.0
18					100.0	98.9	98.3	94.6	81.1	82.1	58.7	59.1
19						99.3	99.3	96.3	87.6	86.8	64.7	67.3
20							100.0	97.5	92.2	90.5	71.4	74.4
21								98.4	93.5	93.2	79.7	80.3
22								98.9	96.7	95.2	84.9	85.1
23									98.0	96.7	89.5	89.0
24									98.0	97.7	91.8	91.9
25									98.7	98.5	93.7	94.2
26									99.4	99.0	94.7	95.8
27									99.4	99.3	96.9	97.1
28									100.0	99.5	97.7	97.9
29											100.0	98.7

X=SIMULATION PROBABILITY LEVEL Y=PREDICTED PROBABILITY LEVEL

TABLE 5.7 COEFFICIENT OF VARIATION EQUAL ONE, CASE D

3 SYSTEMS

SPARING CYCLE: PROCESS 2(EXPONENTIAL), PROCESS 3(EXPONENTIAL), PROCESS 1(EXPONENTIAL)

$u(1)=35.0$ $\sigma(1)^2=1225.0$

$u(2)=7.0$ $\sigma(2)^2=49.0$

$u(3)=8.0$ $\sigma(3)^2=64.0$

TIME PERIOD	PREDICTION TECHNIQUE		SIMULATION						COMPARISON	
	u_p	σ_s	u_s	σ_s	N.S.	D.F.	χ^2 VALUE	α LEVEL	u_p/u_s	σ_p/σ_s
50	3.20	1.42	3.10	1.39	224	5	3.15	.5	1.03	1.02
100	6.20	1.90	6.16	1.91	228	6	7.08	.3	1.01	0.99
150	9.20	2.29	9.31	2.29	212	7	14.33	.025	1.00	1.00
200	12.20	2.61	12.20	2.63	208	9	6.95	.5	1.00	0.99
250	15.20	2.90	15.35	2.87	217	10	11.50	.3	0.99	1.01
300	18.20	3.17	18.24	3.28	208	12	14.04	.2	1.00	1.00
350	21.20	3.41	21.09	3.79	215	14	8.55	.8	1.01	0.90
400	24.20	3.64	24.27	3.57	217	13	15.07	.3	1.00	1.02
450	27.20	3.85	26.86	3.92	207	14	8.77	.8	1.01	0.98
500	30.20	4.06	29.94	3.80	206	14	20.78	.1	1.01	1.07

N.S. NUMBER OF SIMULATIONS
D.F. DEGREES OF FREEDOM
( ) PROCESS

TABLE 5.8 COEFFICIENT OF VARIATION EQUAL ONE, CASE D

TIME PERIODS

SPARE LEVEL	50		100		150		200		250		300	
	X	Y	X	Y	X	Y	X	Y	X	Y	X	Y
3	62.5	65.5										
4	82.6	83.6										
5	95.5	92.8										
6	100.0	96.9	60.5	61.6								
7			78.1	77.8								
8			88.6	88.2								
9			95.6	94.6	57.6	59.7						
10			97.4	97.1	70.3	74.2						
11			99.1	98.6	83.0	84.6						
12					92.9	91.3	53.4	58.5				
13					96.2	95.3	69.2	71.7				
14					98.6	97.6	79.3	81.9				
15							88.0	89.0	51.6	57.7		
16							95.7	93.6	68.2	69.6		
17							98.6	96.4	77.0	79.7		
18							99.5	98.0	86.2	86.9	58.2	57.0
19									92.6	91.9	69.7	68.4
20									95.9	95.2	76.4	77.9
21									98.6	97.2	82.2	85.1
22									99.5	98.4	88.0	90.4
23											95.2	94.0
24											96.2	96.4
25											98.1	97.9

X=SIMULATION PROBABILITY LEVEL Y=PREDICTED PROBABILITY LEVEL

TABLE 5.8 (continued) COEFFICIENT OF VARIATION EQUAL ONE, CASE D

TIME PERIODS

SPARE LEVEL	350		400		450		500	
	X	Y	X	Y	X	Y	X	Y
21	55.2	56.5						
22	62.6	67.3						
23	71.5	76.4						
24	80.0	83.6	53.9	56.1				
25	87.4	89.0	65.9	66.3				
26	93.0	92.9	72.8	75.1				
27	95.3	95.5	83.4	82.2	56.0	55.8		
28	97.2	97.3	88.9	87.7	64.3	65.5		
29	99.1	98.4	93.6	91.8	73.9	73.9		
30			94.9	94.7	82.6	81.0	58.7	55.5
31			98.6	96.6	87.4	86.5	68.0	64.7
32			99.5	97.8	91.3	90.8	74.8	72.9
33					95.7	93.8	81.1	79.9
34					98.1	96.0	86.9	85.5
35					99.0	97.4	91.8	89.8
36							96.6	93.6
37							98.1	95.3
38							99.5	96.9

X=SIMULATION PROBABILITY LEVEL Y=PREDICTED PROBABILITY LEVEL

Coefficient of Variation Less Than One

The third area of interest was concerned with the coefficient of variation of the process being less than one and the process density functions shewed right. The Weibull probability density function of time to failure was used for each of the three processes.

The mean values of each process were the same as they had been in all of the previous cases. The Weibull probability density function has been defined in Equation 5.1. For the process probability density function to be skewed right the shape parameter, B, was made greater than one. Then by using the mean value for a process and picking a shape parameter value the scale parameter was found. Then the variance was determined.

This area of interest was also studied in two separate cases. The two cases had the same parameters for the second and third processes. The difference in the two was that the first process, Case E, had a variance of 426.64 while Case F had a variance of 96.4. The two cases had the same mean for the first process.

Case E is presented in Table 5.9. These results show the lowest α level was .05. The probability levels and the corresponding spare levels of Case E are in Table 5.10. These results show varying patterns. The probability levels do not show a direct correspondence between the prediction

technique and the simulation for a sparing level. The results in Table 5.10 do show a slight trend. From 50 per cent to approximately 93 per cent if a probability level is picked then the discrepancy between the sparing levels will not be more than one spare.

Case F decreased the variance of the first process and these results are in Table 5.11. The degrees of freedom should be noted in this case. At the time period of 50 the simulation gave no degrees of freedom so the Chi-Squared test could not be performed. As the time increment increased, the degrees of freedom did not become increasingly larger for the time periods presented. The range of the α level was between .025 and .3.

The probability levels and corresponding spare levels of this case are presented in Table 5.12. These probability levels show a marked pattern. Irregardless of the time period, the predicted probability for a spare level is equal to or larger than the corresponding simulation probability. The exception to this fact occurs in the lower probability levels for the time periods of 500 and 550. Throughout this table there is never a difference of more than one spare for a desired probability level between the simulation and predicted results.

TABLE 5.9 COEFFICIENT OF VARIATION LESS THAN ONE, CASE E

3 SYSTEMS

SPARING CYCLE: PROCESS 2(WEIBULL), PROCESS 3(WEIBULL), PROCESS 1(WEIBULL)

u(1)=35.0	$\sigma(1)^2$=426.04	B(1)=1.75	A(1)=616.82	σ/u=.59
u(2)=7.0	$\sigma(2)^2$=13.38	B(2)=2.0	A(2)=62.39	σ/u=.52
u(3)=8.0	$\sigma(3)^2$=17.48	B(3)=2.0	A(3)=81.49	σ/u=.52

TIME PERIOD	PREDICTION TECHNIQUE		SIMULATION						COMPARISON	
	u_p	σ_p	u_s	σ_s	N.S.	D.F.	X^2 VALUE	α LEVEL	u_p/u_s	σ_p/σ_s
50	2.67	0.99	2.64	1.05	325	3	0.896	.8	1.01	0.94
100	5.67	1.23	5.66	1.18	168	3	1.37	.7	1.00	1.05
150	8.67	1 44	8.59	1.33	118	3	3.13	.3	1.01	1.08
200	11.67	1.62	11.71	1.68	133	4	0.905	.9	0.99	0.96
250	14.67	1.78	14.95	1.92	127	6	4.45	.5	0.98	0.93
300	17.67	1.93	17.56	1.87	128	5	8.36	.1	1.01	1.03
350	20.67	2.06	20.46	1.94	122	5	2.07	.8	1.01	1.07
400	23.67	2.19	23.37	2.48	122	7	8.40	.2	1.01	0.88
450	26.67	2.32	26.81	2.53	127	8	12.82	.1	1.00	0.92
500	29.67	2.43	29.66	2.26	121	6	5.41	.3	1.00	1.02
550	32.67	2.54	32.37	2.39	115	7	13.41	.05	1.01	1.06
600	35.67	2.65	35.39	2.83	112	8	7.03	.5	1.01	0.93

N.S. NUMBER OF SIMULATIONS
D.F. DEGREES OF FREEDOM
( ) PROCESS

TABLE 5.10 COEFFICIENT OF VARIATION LESS THAN ONE, CASE E

TIME PERIODS

SPARE LEVEL	50		100		150		200		250		300	
	X	Y	X	Y	X	Y	X	Y	X	Y	X	Y
3	79.4	86.4										
4	96.9	97.9										
5	100.0	99.7										
6			76.8	79.4								
7			95.2	94.5								
8			99.4	98.9								
9			100.0	99.8	78.8	75.3						
10					92.4	91.3						
11					99.2	97.6						
12					100.0	99.4	68.4	72.5				
13							87.2	88.6				
14							94.7	96.1				
15							97.7	98.9	64.6	70.5		
16									78.7	86.3		
17									90.6	94.7	53.9	48.1
18									96.1	98.2	71.1	68.9
19									99.2	99.5	83.6	84.3
20											92.2	93.2
21											98.4	97.5
22											100.0	99.2

X=SIMULATION PROBABILITY LEVEL Y=PREDICTED PROBABILITY LEVEL

TABLE 5.10 (continued) COEFFICIENT OF VARIATION LESS THAN ONE, CASE E

TIME PERIODS

SPARE LEVEL	350		400		450		500		550		600	
	X	Y	X	Y	X	Y	X	Y	X	Y	X	Y
20	53.3	48.3										
21	70.5	67.7										
22	86.1	82.6										
23	94.3	91.9	54.1	48.4								
24	97.5	96.7	68.9	66.6								
25	99.2	98.8	82.8	81.1								
26			90.2	90.6	51.2	48.5						
27			95.1	95.8	65.4	65.7						
28			97.5	98.3	76.4	79.8						
29			98.4	99.4	82.7	89.4	52.1	48.5				
30					90.1	95.0	66.9	65.6				
31					96.1	97.9	77.7	78.6				
32					97.6	99.2	87.6	88.3	54.8	48.6		
33							93.4	94.2	70.4	64.3		
34							99.2	97.4	81.7	77.6		
35							99.2	98.9	92.2	87.2	53.6	48.7
36							100.0		93.0	93.4	63.4	63.8
37									96.5	96.9	75.9	76.7
38									99.1	98.6	89.3	86.3
39											94.7	92.6
40											96.4	96.4
41											98.2	98.3
42											98.2	99.3

X=SIMULATION PROBABILITY LEVEL   Y=PREDICTED PROBABILITY LEVEL

TABLE 5.11 COEFFICIENT OF VARIATION LESS THAN ONE, CASE F

3 SYSTEMS

SPARING CYCLE: PROCESS 2(WEIBULL), PROCESS 3(WEIBULL), PROCESS 1(WEIBULL)

u(1)=35.0	$\sigma(1)^2$=96.40	A(1)=2223233.51	B(1)=4.0	σ/u=.2805
u(2)=7.0	$\sigma(2)^2$=13.38	A(2)=62.30	B(2)=2.0	σ/u=.5226
u(3)=8.0	$\sigma(3)^2$=17.48	A(3)=81.49	B(3)=2.0	σ/u=.5226

TIME PERIOD	PREDICTION TECHNIQUE		SIMULATION						COMPARISON	
	u_p	σ_P	u_s	σ_s	N.S.	D.F.	X^2 VALUE	α LEVEL	u_p/u_s	σ_p/σ_s
50	2.48	0.68	2.81	0.50	138	0			0.88	1.34
100	5.48	0.78	5.60	0.76	157	1	16.31		0.98	1.02
150	8.48	0.87	8.42	0.94	125	1	4.55	.025	1.01	0.93
200	11.48	0.96	11.59	0.94	113	1	1.13	.2	0.99	1.02
250	14.48	1.03	14.56	1.14	117	3	5.76	.1	0.99	0.90
300	17.48	1.11	17.49	1.24	114	3	3.55	.3	1.00	0.89
350	20.48	1.17	20.57	1.32	119	3	2.67	.3	1.00	0.89
400	23.48	1.24	23.43	1.51	115	3	12.80	.005	1.00	0.82
450	26.48	1.30	26.45	1.48	116	3	7.77	.05	1.00	0.86
500	29.48	1.35	29.41	1.50	115	3	3.96	.2	1.00	0.90
550	32.48	1.41	32.39	1.41	111	3	5.99	.1	1.00	1.00

N.S. NUMBER OF SIMULATIONS
D.F. DEGREES OF FREEDOM
( ) PROCESS

TABLE 5.12 COEFFICIENT OF VARIATION LESS THAN ONE, CASE F

TIME PERIODS

SPARE LEVEL	50		100		150		200		250		300	
	X	Y	X	Y	X	Y	X	Y	X	Y	X	Y
3	98.6	99.4										
4	99.3	100.0										
5	100.0											
6			94.3	96.8								
7			99.4	100.0								
8			100.0									
9					91.2	93.6						
10					100.0	99.7						
11												
12							85.0	90.7				
13							98.2	99.3				
14							100.0	100.0				
15									82.9	88.2		
16									96.6	98.7		
17									100.0	100.0	50.0	52.0
18											82.5	86.1
19											95.6	98.0
20											100.0	99.8

X=SIMULATION PROBABILITY LEVEL Y=PREDICTED PROBABILITY LEVEL

TABLE 5.12 (continued) COEFFICIENT OF VARIATION LESS THAN ONE, CASE F

TIME PERIODS

SPARE LEVEL	350		400		450		500		550	
	X	Y	X	Y	X	Y	X	Y	X	Y
20	50.4	51.9								
21	77.3	84.3								
22	90.8	97.2								
23	99.2	99.7	51.3	51.7						
24	100.0		83.5	82.7						
25			92.2	96.4						
26			99.1	99.5						
27			100.0	100.0	77.6	81.3				
28					96.6	95.6				
29					100.0	99.3	53.0	51.6		
30							80.9	80.0		
31							91.3	94.7		
32							96.5	99.1	59.5	51.5
33							99.1	100.0	78.4	78.9
34							100.0		91.0	93.9
35									98.2	98.8
36									10C.0	99.8

X=SIMULATION PROBABILITY LEVEL Y=PREDICTED PROBABILITY LEVEL

Process Skewed Left and Skewed Right

The next case concerns the initial process being skewed left, the second process with no skewness, and the third process skewed right. This was accomplished by making the first process parameter those that were used in Case B for the first process. Thus this process had a Weibull probability density function. The second process was set up as a normal density function with the mean that had been previously used for that process. The variance for the second process was chosen so the coefficient of variation would be less than one. The third process was set up with the parameters of the third process of Case E.

These three processes make up one system. There were three systems used to create Case G and the results are in Tables 5.13 and 5.14. In Table 5.13 the α level can be seen to never vary below .1. Each time period has at least five degrees of freedom for these α level tabulations.

Table 5.14 presents the probability levels and sparing levels. These results show a trend that as the time periods increase the difference in spares between the prediction technique and the simulation decreases. That is, for a desired probability level as the time periods increase the spare level associated with the prediction will become closer to that of the simulation.

TABLE 5.13 PROCESS SKEWED LEFT AND SKEWED RIGHT, CASE G

3 SYSTEMS

SPARING CYCLE: PROCESS 2(NORMAL), PROCESS 3(WEIBULL), PROCESS 1(WEIBULL)

u(1)=35.0	$\sigma(1)^2$=2242.0	σ/u=1.35
u(2)=7.0	$\sigma(2)^2$=25.0	σ/u=.71
u(3)=8.0	$\sigma(3)^2$=17.48	σ/u=.52

TIME PERIOD	PREDICTION TECHNIQUE		SIMULATION						COMPARISON	
	u_p	σ_p	u_s	σ_s	N.S.	D.F.	X^2 VALUE	α LEVEL	u_p/u_s	σ_p/σ_s
50	3.77	1.28	3.62	1.51	270	5	7.80	.1	1.04	0.85
100	6.77	2.09	6.53	2.25	185	7	6.53	.3	1.04	0.93
150	9.77	2.67	8.82	2.56	179	7	4.03	.7	1.11	1.18
200	12.77	3.14	12.42	3.14	146	10	16.47	.1	1.03	1.00
250	15.77	3.55	15.37	3.60	139	11	9.61	.5	1.03	0.99
300	18.77	3.92	19.32	3.98	139	13	6.12	.9	0.97	0.98
350	21.77	4.25	21.27	4.07	142	13	11.54	.5	1.02	1.04
400	24.77	4.56	24.00	4.79	150	16	10.52	.8	1.03	0.95

N.S. NUMBER OF SIMULATIONS
D.F. DEGREES OF FREEDOM
( ) PROCESS

TABLE 5.14 PROCESSES SKEWED LEFT AND SKEWED RIGHT, CASE G

TIME PERIODS

SPARE	50		100		150		200	
	X	Y	X	Y	X	Y	X	Y
4	73.3	71.1						
5	89.6	82.5						
6	96.7	89.7						
7	99.3	93.9	66.5	67.0				
8	100.0		81.1	77.7				
9			93.0	85.4	61.5	52.4		
10			95.7	90.7	77.1	64.6		
11			97.8	94.1	89.4	74.5		
12			99.5	96.3	95.5	82.2	54.1	52.1
13			99.5		98.9	87.9	65.1	63.0
14					99.4	91.9	78.1	72.2
15					99.4	94.7	83.6	79.8
16					100.0	96.6	87.0	85.6
17							93.8	89.9
18							96.6	93.1
19							98.6	95.3
20							99.3	96.9
21							100.0	

X=SIMULATION PROBABILITY LEVEL Y=PREDICTED PROBABILITY LEVEL

TABLE 5.14 (continued) PROCESSES SKEWED LEFT AND SKEWED RIGHT, CASE G

TIME PERIODS

SPARE	250 X	250 Y	300 X	300 Y	350 X	350 Y	400 X	400 Y
16	60.4	61.8						
17	69.1	70.5						
18	78.4	77.8						
19	87.7	83.6	51.8	60.9				
20	92.1	88.2	63.3	69.1				
21	96.4	91.[illegible]	71.2	76.1				
22	97.8	94.1	78.4	81.9	61.3	60.2		
23	99.3	95.9	84.9	86.6	69.0	67.9		
24	99.3	97.2	92.1	90.2	78.2	74.7		
25	100.0		94.2	93.0	87.3	80.5		
26			97.1	95.0	90.1	85.2	61.3	59.6
27			97.8	96.5	95.8	88.9	67.3	67.0
28			99.3		95.8	91.8	78.0	73.5
29			100.0		96.5	94.1	85.3	79.2
30					100.0	95.7	89.3	83.9
31							91.9	87.7
32							94.0	90.8
33							95.3	93.2
34							95.3	95.0
35							96.7	96.4
36							99.3	97.4
37							99.3	
							100.0	

X=SIMULATION PROBABILITY LEVEL Y=PREDICTED PROBABILITY LEVEL

Process Density Function Normal

The next area of interest was to set up the processes of the system with normal probability density functions. This was also accomplished in two cases. Case H was to use the mean values and variances of the processes in Case B. The results are presented in Table 5.15.

The α levels show a wide contrast. The first three time periods have low α levels. For the fourth time period the α level could not be obtained. The time periods 300, 550, and 600 also showed low α levels.

The corresponding probability levels and spare levels are presented in Table 5.16. These values show a small trend. From 50 per cent to approximately 90 per cent the difference in spares for a desired probability was one. This trend held for all of the time periods. For a probability level above 90 per cent the difference in spares started to increase. That is, for a predicted sparing probability for a certain sparing level, the simulated value would be larger.

This can be illustrated by observing the time period of 250. For the first part if a probability of 85 per cent of sufficient spares was desired, the prediction technique would require 20 spares. The simulation would require 19 spares. If a probability of 95 per cent of sufficient spares was required the prediction technique would require 23 spares while the simulation would require only 20 spares.

The simulation for Case H was run under the assumption that negative time values would be allowed to occur. This means that if a low enough probability was obtained from the random number generator then a negative time could be associated with it.

In order to explain this consider that the time to failure for the first process occured in zero time. This would give a normalized Z value of -.74. Using normalized tables, 22.96 per cent of the time a Z value of less than this could occur. The Z values for the second and third processes are both -.74.

Thus it would be quite probable that a negative time could be found for any of the processes. This would mean that the spare could have failed before it was put into the system. Instead of being added to the total time the system was being used, this time would be taken away.

Case I was set up using the same parameters as Case H. This case would allow any process to have the negative time increment but these values would be set to zero. Thus all of the times to failure would be zero or positive. This case would have the same prediction values as the unbounded normals.

Case I is in Tables 5.17 and 5.18. The α level for this case is .1 at its lowest value. The predicted values of the mean and standard deviation present a trend when compared to the simulated values. The simulated values are consistently

less than the predicted values.

The corresponding probability levels are presented in Table 5.18. The results of this table show that the predicted probability level is always less than the simulated probability. The results show a marked contrast to those of Case H. That is, the difference between the predicted spare level and the simulated spare level becomes more than one or two spares.

The second part of the test used the means and variances of the processes from Case E. These values were used with normal probability density functions. These results are presented in Tables 5.19 and 5.20.

Table 5.19 shows the first set of results. The α level has a wide range; the α level exceeds the .05 level only in three cases. These are the time periods of 50, 350, and 450.

The corresponding probability levels and sparing levels are in Table 5.20. The α levels in these results did not show promising results. But the probability levels showed a very good correspondence. At the lower time periods from 50 to 250 the predicted probability level for a spare was generally larger than the simulation. This is shown by the fact that the prediction probability is closer in value to the corresponding probability level than it is to the next simulation probability level.

The coefficients of variation for the simulations were less than one. If a normalized Z value was found at time

zero for the first process it would be -1.7. This would give a probability of 4.46 per cent of obtaining a negative time.

Case K was set up using the values of Case J. The only difference in the two tests was that negative times were not allowed to be tabulated. These values were set to zero. All of the times for the processes were either zero or positive.

Table 5.21 shows the results of the Chi-Squared goodness of fit test. The lowest α level in this test was .025 at the time period 600. Comparing the simulated values with those of Case J in Table 5.19, the mean values of Case K have a tendency to be less than those of Case J. The standard deviations are variable, without a pattern developing.

The probability levels for Case K are presented in Table 5.22. These values show that for the first two time periods the prediction probability for a spare level is higher than the simulated value. As the time periods increased, the predicted probability levels fell below the simulated values.

TABLE 5.15 PROCESS DENSITY FUNCTION NORMAL, CASE H

3 SYSTEMS

SPARING CYCLE: PROCESS 2(NORMAL), PROCESS 3(NORMAL), PROCESS 1(NORMAL)

u(1)=35.0	$\sigma(1)^2$=2242.03	σ/u=1.35
u(2)=7.0	$\sigma(2)^2$=89.68	σ/u=1.35
u(3)=8.0	$\sigma(3)^2$=117.13	σ/u=1.35

TIME PERIOD	PREDICTION TECHNIQUE		SIMULATION						COMPARISON	
	u_p	σ_p	u_s	σ_s	N.S.	D.F.	X^2 VALUE	α LEVEL	u_p/u_s	σ_p/σ_s
50	3.87	2.77	2.97	1.91	142	6	22.66	.001	1.30	1.45
100	6.87	3.26	6.36	2.44	189	8	17.78	.02	1.08	1.33
150	9.87	3.68	9.53	2.89	168	9	25.06	.001	1.04	1.27
200	12.87	4.06	11.99	3.62	180	12	40.41		1.07	1.12
250	15.87	4.41	14.92	3.72	157	12	12.47	.3	1.06	1.17
300	18.87	4.73	18.03	4.43	158	15	32.16	.005	1.05	1.68
350	21.87	5.03	20.16	4.13	138	14	15.12	.3	1.08	1.22
400	24.87	5.31	24.52	5.35	143	19	19.03	.3	1.01	0.99
450	27.87	5.58	27.04	5.02	137	17	14.45	.5	1.03	1.11
500	30.87	5.84	30.18	5.33	137	18	15.57	.5	1.02	1.10
550	33.87	6.09	33.50	6.31	132	21	34.08	.025	1.01	0.96
600	36.87	6.32	35.86	6.07	139	21	35.28	.025	1.03	1.04

N.S. NUMBER OF SIMULATIONS
D.F. DEGREES OF FREEDOM
( ) PROCESS

TABLE 5.16 PROCESS DENSITY FUNCTION NORMAL, CASE H

TIME PERIODS

SPARE LEVEL	50		100		150		200		250		300	
	X	Y	X	Y	X	Y	X	Y	X	Y	X	Y
3	68.3	52.5										
4	80.3	69.8										
5	88.7	81.4										
6	93.0	88.7	57.7	51.8								
7	98.6	93.2	68.3	65.7								
8	99.3	95.9	77.3	76.5								
9	100.0	97.6	88.4	84.3	53.6	51.5						
10			94.2	89.7	64.9	63.5						
11			97.4	93.4	75.6	73.4						
12			100.0	95.8	82.7	81.1	59.4	51.3				
13					89.3	86.9	68.3	61.9				
14					94.1	91.1	77.8	71.1				
15					97.6	94.0	88.4	78.6				
16					99.4	96.0	88.9	84.5	68.8	60.8		
17					99.4	97.4	90.6	89.0	76.4	69.4		
18					99.4	98.3	93.9	92.3	81.5	76.6	57.6	51.1
19							96.1	94.7	89.8	82.5	67.1	60.0
20							97.2	96.4	95.5	87.1	70.1	68.0
21							97.8	97.5	97.5	90.7	76.0	75.0
22							100.0	98.3	98.1	93.4	84.8	80.8
23									98.1	95.3	90.0	85.5
24									98.1	96.8	90.5	89.3
25									99.4	97.8	92.4	92.1
26											94.9	94.3
27											95.6	95.9
28											98.7	97.1

X=SIMULATION PROBABILITY LEVEL Y=PREDICTED PROBABILITY LEVEL

TABLE 5.16 (continued) PROCESS DENSITY FUNCTION NORMAL, CASE H

TIME PERIODS

SPARE LEVEL	350		400		450		500		550		600	
	X	Y	X	Y	X	Y	X	Y	X	Y	X	Y
21	68.1	51.0										
22	74.6	59.3										
23	79.7	66.9										
24	85.5	73.6	55.9	51.0								
25	89.1	79.4	63.6	58.8								
26	92.0	84.1	69.2	66.0								
27	94.2	87.9	74.1	72.5	54.7	50.9						
28	95.7	91.0	79.0	78.1	62.8	58.4						
29	96.4	93.3	83.9	82.8	70.8	65.2						
30	97.1	95.1	86.0	86.7	75.9	71.5						
31	99.3	96.5	87.4	89.9	81.0	77.0						
32	100.0	97.5	90.2	92.4	85.4	81.7	68.6	64.5				
33			93.7	94.3	87.6	85.6	74.5	70.6	56.1	50.8		
34			95.8	95.8	90.5	88.8	78.1	75.9	60.6	57.6		
35			95.8	96.9	94.2	91.5	82.5	80.6	65.2	64.0		
36			97.2	97.8	96.4	93.5	86.9	84.6	69.7	69.8	56.8	50.8
37			97.9	98.5	96.4	95.1	89.8	87.9	78.0	75.0	65.5	57.3
38			98.6	98.9	97.8	96.4	92.7	90.6	80.3	79.7	70.5	63.5
39			99.3	99.2	98.5	97.3	94.2	92.8	82.6	83.6	74.8	69.1
40					100.0	98.1	97.1	94.5	86.4	87.0	77.7	74.2
41							97.8	95.8	88.6	89.7	82.7	78.8
42							99.3	96.9	90.9	92.0	83.5	82.7
43							100.0	97.7	92.4	93.8	84.9	86.1
44									93.9	95.3	90.7	89.0
45									95.5	96.4	92.8	91.3
46									95.5	97.3	96.4	93.2
47									97.0	98.1	97.1	94.8
48									97.7	98.6	97.1	96.0

X=SIMULATION PROBABILITY LEVEL
Y=PREDICTED PROBABILITY LEVEL

TABLE 5.17 NORMAL PROCESSES CASE I

3 SYSTEMS

SPARING CYCLE: PROCESS 2(NORMAL), PROCESS 3(NORMAL), PROCESS 1(NORMAL)

u(1)=35.0	$\sigma(1)^2$=2242.03	σ/u=1.35
u(2)=7.0	$\sigma(2)^2$=89.68	σ/u=1.35
u(3)=8.0	$\sigma(3)^2$=117.13	σ/u=1.35

TIME	PREDICTION TECHNIQUE		SIMULATION						COMPARISON	
	u_p	σ_p	u_s	σ_s	N.S.	D.F.	X^2 VALUE	α LEVEL	u_p/u_s	σ_p/σ_s
50	3.87	2.77	2.67	1.49	278	5	7.58	.1	1.45	1.86
100	6.87	3.26	5.11	1.86	139	5	8.48	.1	1.35	1.75
150	9.87	3.68	7.47	2.27	156	7	11.52	.1	1.32	1.62
200	12.87	4.06	9.85	2.49	153	8	2.61	.95	1.31	1.63
250	15.87	4.41	13.03	2.54	143	8	13.38	.1	1.22	1.74
300	18.87	4.73	15.41	2.62	146	8	5.83	.5	1.25	1.80
350	21.87	5.03	17.74	2.56	126	7	8.26	.3	1.23	1.96
400	24.87	5.31	20.07	3.16	124	10	12.82	.2	1.24	1.68
450	27.87	5.58	23.04	3.39	134	10	11.28	.3	1.21	1.65
500	30.87	5.84	25.19	3.44	121	11	14.73	.1	1.23	1.70
550	33.87	6.09	27.82	3.43	139	11	16.28	.1	1.22	1.78
600	36.87	6.32	29.84	3.90	141	13	15.94	.2	1.24	1.62

N.S. NUMBER OF SIMULATIONS
D.F. DEGREES OF FREEDOM
( ) PROCESS

TABLE 5.18 NORMAL PROCESSES, CASE I

TIME PERIODS

SPARE LEVEL	50		100		150		200		250		300	
	X	Y	X	Y	X	Y	X	Y	X	Y	X	Y
3	73.4	52.5										
4	89.9	69.8										
5	96.4	81.4	63.3									
6	98.6	88.7	77.7	51.8								
7	100.0	93.2	92.1	65.7								
8			95.7	76.5	69.2							
9			97.8	84.3	82.1	51.5						
10			99.3	89.7	89.7	63.5	60.8					
11					95.5	73.4	76.5					
12					98.1	81.1	86.9	51.3				
13					100.0	86.9	93.5	61.9	54.6			
14							96.7	71.1	72.7			
15							98.0	78.6	84.6	51.2	54.1	
16							99.4	84.5	88.8	60.8	67.1	
17									97.9	68.4	79.5	
18									99.3	76.6	90.4	51.1
19											94.5	60.0
20											95.9	68.0
21											98.6	75.0
22											99.3	80.8
23											99.3	85.5
24											100.0	89.3

X=SIMULATION PROBABILITY LEVEL Y=PREDICTED PROBABILITY LEVEL

TABLE 5.18 (continued) NORMAL PROCESSES, CASE I

TIME PERIODS

SPARE LEVEL	350 X	350 Y	400 X	400 Y	450 X	450 Y	500 X	500 Y	550 X	550 Y	600 X	600 Y
18	64.3											
19	73.8											
20	84.9		62.1									
21	94.4	51.6	71.0									
22	96.8	59.3	81.5									
23	97.6	66.9	86.3		59.9							
24	99.2	73.6	90.3	51.0	67.2							
25	100.0	79.4	92.7	58.8	78.4		52.9					
26			95.2	66.0	85.8		66.1					
27			98.4	72.5	89.6	50.9	76.9					
28			98.4	78.1	93.3	58.4	87.6		59.0			
29			99.2	82.8	97.8	65.2	93.4		66.2			
30			100.0	86.7	97.8	71.5	95.9	50.9	77.7		56.7	
31					98.5	77.6	95.9	58.0	85.6		64.5	
32					99.3	81.7	96.7	64.5	92.8		75.2	
33					100.0	85.6	97.5	76.6	94.2	50.8	82.3	
34							99.2	75.9	97.1	57.6	90.8	
35									98.6	64.0	93.6	
36									99.3	69.9	96.5	56.8
37									100.0	75.0	96.5	57.3
38											98.6	63.5
39											98.6	69.1
40												74.3
41												78.8

X=SIMULATION PROBABILITY LEVEL Y=PREDICTED PROBABILITY LEVEL

TABLE 5.19 NORMAL PROCESSES, CASE J

3 SYSTEMS

SPARING CYCLE: PROCESS 2(NORMAL), PROCESS 3(NORMAL), PROCESS 1(NORMAL)

$u(1)=35.0$ $\sigma(1)^2=426.04$ $\sigma/u=.59$

$u(2)=7.0$ $\sigma(2)^2=13.38$ $\sigma/u=.52$

$u(3)=8.0$ $\sigma(3)^2=17.48$ $\sigma/u=.52$

TIME PERIOD	PREDICTION TECHNIQUE		SIMULATION						COMPARISON	
	u_p	σ_p	u_s	σ_s	N.S.	D.F.	X^2 VALUE	α LEVEL	u_p/u_s	σ_p/σ_s
50	2.67	1.04	2.63	1.00	299	3	10.25	.01	1.02	1.04
100	5.67	1.28	5.68	1.89	136	3	5.30	.1	1.00	1.08
150	8.67	1.48	8.73	1.38	134	3	3.78	.2	0.99	1.07
200	11.67	1.65	11.53	1.44	125	3	1.72	.5	1.01	1.15
250	14.67	1.81	14.77	1.70	123	4	3.84	.3	0.99	1.07
300	17.67	1.96	17.70	1.74	115	4	9.19	.05	1.00	1.12
350	20.67	2.09	20.48	1.90	120	5	16.36	.005	1.01	1.10
400	23.67	2.22	23.65	2.08	123	5	7.02	.2	1.00	1.07
450	26.67	2.34	26.44	2.16	118	6	13.46	.025	1.01	1.08
500	29.67	4.15	29.66	2.05	115	5	8.03	.1	1.00	1.20

N.S. NUMBER OF SIMULATIONS
D.F. DEGREES OF FREEDOM
( ) PROCESS

TABLE 5.20 NORMAL PROCESSES, CASE J

TIME PERIODS

SPARE LEVEL	50		100		150		200		250		300	
	X	Y	X	Y	X	Y	X	Y	X	Y	X	Y
3	81.6	86.4										
4	98.7	97.9										
5	100.0	99.7										
6			80.1	79.4								
7			94.1	94.5								
8			97.8	98.9								
9			98.5	99.8	75.4	75.3						
10			99.9		88.8	91.3						
11					97.0	97.6						
12					99.3	99.4	73.6	72.5				
13					100.0		92.8	88.6				
14							98.4	96.1				
15							99.2	98.9	65.0	70.5		
16							100.0	99.[illegible]	82.9	86.3		
17									95.9	94.7	52.2	48.1
18									99.2	98.2	65.2	68.9
19									100.0	99.5	84.3	84.3
20											94.8	93.2
21											98.3	97.5
22											100.0	99.2

X=SIMULATION PROBABILITY LEVEL　　Y=PREDICTED PROBABILITY LEVEL

TABLE 5.20(continued) NORMAL PROCESSES, CASE J

TIME PERIODS

SPARE LEVEL	350		400		450		500	
	X	Y	X	Y	X	Y	X	Y
20	56.7	48.3						
21	75.8	67.7						
22	86.7	82.6						
23	90.8	91.9						
24	96.7	96.7	69.1	66.6				
25	99.2	98.8	81.3	81.1				
26	100.0		91.9	90.6	56.8	48.5		
27			96.7	95.8	76.3	65.7		
28			99.2	98.3	80.5	79.8		
29			100.0	99.4	88.9	89.4	53.9	48.5
30					96.6	95.0	72.2	65.0
31					98.3	97.9	82.6	78.6
32					99.2	99.2	91.3	88.3
33					100.0		94.8	94.2
34							98.3	97.4
35							98.3	98.9
36							99.1	
37							100.0	

X=SIMULATION PROBABILITY LEVEL Y=PREDICTED PROBABILITY LEVEL

TABLE 5.21 NORMAL PROCESSES, CASE K

3 SYSTEMS

SPARING CYCLE: PROCESS 2(NORMAL), PROCESS 3(NORMAL), PROCESS 1(NORMAL)

$u(1)=35.0$	$\sigma(1)^2=426.04$	$\sigma/u=.59$
$u(2)=7.0$	$\sigma(2)^2=13.38$	$\sigma/u=.52$
$u(3)=8.0$	$\sigma(3)^2=17.48$	$\sigma/u=.52$

TIME PERIOD	PREDICTION TECHNIQUE		SIMULATION						COMPARISON	
	u_p	σ_p	u_s	σ_s	N.S.	D.F.	X^2 VALUE	α LEVEL	u_p/u_s	σ_p/σ_s
50	2.67	1.04	2.76	1.01	224	2	3.27	.1	0.97	1.04
100	5.67	1.28	5.82	1.33	130	3	0.71	.05	0.98	0.96
150	8.67	1.48	8.36	1.36	122	3	1.41	.7	1.04	1.09
200	11.67	1.65	11.42	1.64	123	4	6.50	.1	1.02	1.01
250	14.67	1.81	14.53	1.70	126	5	8.56	.1	1.01	1.06
300	17.67	1.96	17.53	1.60	118	3	2.34	.5	1.01	1.23
350	20.67	2.09	20.09	1.68	117	4	8.02	.05	1.03	1.25
400	23.67	2.22	23.10	2.00	124	6	1.80	.9	1.02	1.11
450	26.67	2.34	26.18	2.39	113	6	5.30	.5	1.02	0.98
500	29.67	2.45	29.52	1.92	124	5	5.75	.3	1.01	1.28
550	32.67	2.56	32.23	2.33	117	6	4.86	.5	1.01	1.11
600	35.67	2.67	35.21	2.46	117	7	15.23	.025	1.01	1.08

N.S. NUMBER OF SIMULATIONS
D.F. DEGREES OF FREEDOM
( ) PROCESS

TABLE 5.22 NORMAL PROCESSES, CASE K

TIME PERIODS

SPARE LEVEL	50		100		150		200		250		300	
	X	Y	X	Y	X	Y	X	Y	X	Y	X	Y
3	79.9	86.4										
4	95.1	97.9										
5	100.0	99.7										
6			70.8	79.4								
7			89.2	94.5								
8			98.5	98.9	54.1							
9			100.0	99.8	82.0	75.3						
10					95.9	91.3						
11					98.4	97.6	57.7					
12					99.2	99.4	72.4	72.5				
13					100.0		87.8	88.6				
14							97.6	96.1	51.6			
15							99.2	98.9	73.8	70.5		
16							100.0	99.7	88.1	86.3		
17									93.7	94.7		
18									97.6	98.2	74.6	68.9
19									100.0	99.5	89.8	84.3
20											98.3	93.2
21											98.3	97.5
22											100.0	99.2

X=SIMULATION PROBABILITY LEVEL   Y=PREDICTED PROBABILITY LEVEL

Unequal Time Periods

This test was performed by using the three basic systems composed of three processes each. The three processes were set up with the exponential probability density function of time to failure. These exponentials were set up with the same parameters as were in Case D, Table 5.7.

The difference between this test and the test in Case D was that for Case L the third system was required to operate for a larger time period. This was accomplished by requiring the third system to operate for 100 more time units than the first two systems were to operate. The results are shown in Table 5.23 and Table 5.24.

The α level in Table 5.23 shows that the lowest α level reached is .05. This was found at the time period of 100 or two multiples of the systems' mean life. It should be noted that this time period was listed as 100, but only two of the systems were required to operate for this length of time. The third system was required to last for 200 time units.

The probability levels and corresponding spare levels are given in Table 5.24. This table shows a varying pattern for time periods between 50 and 350. This pattern takes the form that for probability levels in the 80 per cent range for the same spare level the predicted value will be larger than the simulated value. From the rest of the 80 per cent range the predicted value will be less than the simulated value.

TABLE 5.22(continued) NORMAL PROCESSES, CASE K

TIME PERIODS

SPARE LEVEL	350		400		450		500		550		600	
	X	Y	X	Y	X	Y	X	Y	X	Y	X	Y
20	64.0	48.3										
21	76.1	67.7										
22	93.2	82.6										
23	97.4	91.9	60.5									
24	99.2	96.7	75.[illegible]	66.6								
25	100.0	98.8	87.1	81.1								
26			95.2	90.6	57.5	48.5						
27			97.6	95.8	75.2	65.7						
28			100.0	98.3	82.3	79.8						
29					91.2	89.4	51.6	48.5				
30					95.6	95.0	65.3	65.0				
31					99.1	97.9	84.7	78.6				
32					99.1	99.2	96.0	88.3	57.3			
33					100.0		98.4	94.2	70.9	64.3		
34							100.0	97.4	84.6	77.6		
35									89.7	87.2	54.7	
36									95.7	93.4	75.2	63.8
37									99.2	96.9	82.1	76.7
38									100.0	98.6	89.7	86.3
39											92.3	92.6
40											97.4	96.4
41											100.0	98.3

X=SIMULATION PROBABILITY LEVEL Y=PREDICTED PROBABILITY LEVEL

Starting at time period 400 and above another pattern emerges. In this pattern all of the predicted values of probabilities are less than the corresponding simulated values for a spare level.

The conclusions that were drawn from these results are presented in Chapter VI. A summary of the results and further areas of interest are also given.

TABLE 5.23 SYSTEM TIMES VARIED, CASE L

3 SYSTEMS

SPARING CYCLE: PROCESS 2(EXPONENTIAL), PROCESS 3(EXPONENTIAL), PROCESS 1(EXPONENTIAL)

$u(1)=35.0$ $\sigma(1)^2=1225.0$

$u(2)=7.0$ $\sigma(2)^2=49.0$

$u(3)=8.0$ $\sigma(3)^2=64.0$

TIME PERIOD	PREDICTION TECHNIQUE		SIMULATION						COMPARISON	
	u_p	σ_p	u_s	σ_s	N.S.	D.F.	χ^2 VALUE	α LEVEL	u_p/u_s	σ_p/σ_s
50	5.20	1.76	5.10	1.65	148	4	2.54	.5	1.02	1.07
100	8.20	2.17	8.17	2.29	161	7	13.74	.05	1.00	0.95
150	11.20	2.51	11.41	2.60	138	9	3.59	.9	0.98	0.93
200	14.20	2.81	14.54	2.69	147	9	10.48	.3	0.98	1.05
250	17.20	3.08	17.44	2.86	146	9	7.39	.5	0.99	1.08
300	20.20	3.33	20.03	3.27	124	10	3.09	.975	1.01	1.02
350	23.20	3.57	23.54	3.54	130	11	6.49	.8	0.99	1.01
400	26.20	3.78	26.09	3.54	120	11	5.03	.9	1.00	1.07
450	29.20	3.99	28.84	3.91	134	13	10.57	.5	1.01	1.02
500	32.20	4.19	32.46	4.21	119	13	7.04	.9	0.99	0.99
550	35.20	4.37	34.63	4.58	141	15	13.78	.5	1.02	0.96
600	38.20	4.55	37.80	4.48	122	14	13.02	.995	1.01	1.02

N.S. NUMBER OF SIMULATIONS
D.F. DEGREES OF FREEDOM
( ) PROCESS

TABLE 5.24 SYSTEM TIMES VARIED, CASE L

TIME PERIODS

SPARE LEVEL	50		100		150		200		250		300	
	X	Y	X	Y	X	Y	X	Y	X	Y	X	Y
5	61.5	62.6										
6	79.7	79.5										
7	94.6	89.6										
8	97.3	95.0	54.7	60.3								
9	99.3	97.7	71.4	75.3								
10	100.0	99.0	85.7	85.8								
11			91.9	92.2	51.5	58.9						
12			96.9	96.0	68.1	72.5						
13			98.1	98.0	80.0	82.8						
14			99.4	99.0	87.0	89.8						
15			100.0	99.5	93.5	94.2	64.0	70.5				
16					97.1	96.8	76.9	80.4				
17					98.6	98.3	87.1	87.6				
18					99.3	99.2	93.2	92.5	61.6	68.9		
19					100.0	99.6	96.6	95.7	74.0	78.5		
20							98.6	97.6	85.6	85.8	55.7	56.7
21							98.6	98.7	93.2	91.0	66.9	67.7
22							100.0	99.3	97.3	94.5	78.2	76.9
23									100.0	96.7	86.3	84.1
24											91.1	89.5
25											94.4	93.3
26											97.6	95.9
27											99.2	97.5
28											100.0	98.6

X=SIMULATION PROBABILITY LEVEL   Y=PREDICTED PROBABILITY LEVEL

TABLE 5.24(continued) SYSTEM TIMES VARIED, CASE L

TIME PERIODS

SPARE LEVEL	350		400		450		500		550		600	
	X	Y	X	Y	X	Y	X	Y	X	Y	X	Y
23	51.5	56.3										
24	62.3	66.6										
25	71.5	75.5										
26	80.0	82.7	56.7	55.9								
27	87.7	88.2	68.3	65.8								
28	91.5	92.2	75.8	74.3								
29	93.9	95.0	84.2	81.4	56.7	55.6						
30	97.7	96.9	90.8	87.0	67.2	65.0						
31	98.5	98.1	94.2	91.1	77.6	73.3						
32	100.0	98.9	96.7	94.2	85.8	80.3						
33			97.5	96.2	88.8	85.9	56.3	64.4				
34			98.3	97.6	92.5	90.2	66.4	72.4				
35			98.3	98.6	95.5	93.3	75.6	79.2	58.9	55.1		
36			98.3	99.1	97.8	95.6	83.2	84.8	66.0	63.8		
37			100.0	99.5	98.5	97.2	89.1	89.2	72.3	71.6		
38					98.5	98.2	95.0	92.5	81.6	78.3	58.2	54.9
39					99.3	98.9	96.6	95.0	85.1	83.9	65.6	63.3
40					99.3	99.3	97.5	96.7	88.7	88.3	72.1	70.9
41					99.3	99.6	99.2	97.8	91.5	91.8	79.5	77.5
42					100.0	99.8	100.0	98.6	93.6	94.3	84.4	83.0
43									96.5	96.2	89.4	87.5
44									99.3	97.5	93.4	91.0
45									99.3	98.4	95.9	93.7
46									100.0	99.0	96.7	95.7
47											97.5	97.1
48											98.4	98.1
49											98.4	98.7
50											100.0	99.2

X=SIMULATION PROBABILITY LEVEL Y=PREDICTED PROBABILITY LEVEL

CHAPTER VI

CONCLUSIONS

The purpose of this chapter will be to draw conclusions from the results. These conclusions will be presented in the same order as the results were presented.

The first area studied was the case where the coefficient of variation of the process was greater than one and the process density functions were skewed left. These two results were presented in Case A and Case B in Tables 5.1 through 5.4. The coefficient of variation was larger for Case A than for Case B.

The Chi-Squared goodness of fit test is a test of rejection. This means that if a α level is chosen and a test is run where the α level is less than that desired then there is enough information available to reject the hypothesis that the density function under test is normal at that level.

If a α level of .05 is assumed for Case A in Table 5.1 then there would be two time periods where there would be enough information to reject the hypothesis that the spares' configuration was normally distributed. These two time periods where the hypothesis was rejected are at multiples of three and eight times the mean process cycle length. Case B in Table 5.3 shows one time period where the hypothesis of normality was rejected. This was at one multiple of the

process cycle length.

Thus for Case A only two out of eight time periods show enough information to reject the hypothesis that the simulated spares configuration was not normal. Case B has only one out of eleven time periods where there would be enough information to reject the hypothesis of normality. It would then be feasible that the spares configuration obtained using the Weibull probability density function would be normally distributed.

Case A and Case B can be compared by the ratio of their predicted mean values to the simulated mean value for a time period. These results are found in Tables 5.1 and 5.3. These results show that for corresponding time periods the ratios of mean for Case B are closer to a value of unity. The same results hold for the comparisons of the standard deviations. It should be noted that the ratios of both the means and standard deviations were both tending toward a value of unity for Case A and Case B. Thus the prediction technique obtains better results as the time periods become larger multiples of the sparing cycle mean life.

For the general case of the coefficient of variation for each process being greater than one, and the process skewed left, the results from the prediction technique for a sparing level will be less than the actual or simulated probability. Depending upon the probability level of sufficient spares desired, the prediction technique will require at least enough

spares and usually more spares than are necessary. The more multiples of the mean life of the sparing cycle involved in a system the better the results will be.

The prediction technique tends to give better results if the coefficient of variation of each process is close to unity, and if the coefficient of variation of the sparing cycle is less than one. That is, the difference between the number of spares required by the prediction technique and the simulation will be smaller. By doing this, the prediction technique would have a smaller overshoot of the true spare level. This was shown as a direct result of the comparison of Case A and Case B.

The second area of interest was where the coefficient of variation was equal to one. This was accomplished in Case C and Case D in Tables 5.5 through 5.8. Assuming a α level of rejection of .05 then none of the tested time increments for Case C in Table 5.5 show enough information to reject the hypothesis of normality. Using a α level of .05, Case D in Table 5.7 shows that only at one time increment would there be enough information to reject the hypothesis of normality. The time period where there was enough information in Table 5.7 occurred at the time period 150. The time periods on either side of this period were well within the .05 α level. Thus it would be safe to assume that the spares configuration obtained using the exponential probability density function of time to failure would be normally distributed.

Case D does show a more definite pattern than does Case C. Comparing the ratios of means in Case D to those in Case C, Case D appears to be more stable and it approaches a value of unity at a faster rate as the time period increases. The same comparisons can be made of the two separate ratios of standard deviations.

Therefore when the coefficient of variation for the processes of a system is one, the prediction technique gives better results as the number of processes per system is increased. The prediction technique shows closer values to the simulation as the number of time increments are increased.

When a probability level of sufficient spares is desired less than 70 per cent, the prediction technique shows a low estimate of the number of spares. This occurs when the desired time of use is less than eight multiples of the sparing cycle mean life. To correct this it would be possible to add an extra spare. This would cause a situation where the actual probability level was met or at the most exceeded by one spare.

When a probability level above the 80 per cent level is desired the prediction technique will always give safe results. That is, for a sparing level, the simulated probability will be greater than the predicted probability.

The third area of interest was where the coefficient of variation for each process was less than one and the process was skewed right. These results were those in Case E and

Case F in Tables 5.9 through 5.12. Using the α level of .05 there were no time periods where the sparing configuration could be rejected as not being normal for Case E in Table 5.9. With this the ratio of the mean values showed a tendency to go to unity as the time periods increased. The ratio of standard deviations showed no such tendency though. This ratio varied but the amount of variation was small; from .8832 to 1.0812.

Case F in Table 5.11 showed three time periods where there was enough information to reject the hypothesis of normality for the sparing configuration. Two of these occurred at low time increments where the degrees of freedom were zero and one respectively. Since the coefficient of variation is less than one at the low multiples of the mean sparing cycle there was not enough information to run the test. Assuming that normality is not rejected at time period 150 and larger then the ratio of means starts to approach unity. The variation in the ratio of standard deviations is consistently less than unity but as the time increments increase they approach unity.

When the coefficient of variation is less than one, the range of spare levels is not large for the probability levels from 50 per cent and upward. This range does increase as the time periods increase. For low multiples of the sparing cycle mean the prediction technique will give larger probability levels than the simulated level. Since the difference

in probability is small compared to the difference of the next probability level, the prediction technique would give compatible results.

The fourth area of interest was where the process density functions were skewed left and right. These results were those of Case G in Tables 5.13 and 5.14. Using the .05 α level none of the sparing configurations for the different time periods can be rejected as not being normal. The ratio of means and standard deviations show a tendency toward unity.

The prediction technique as presented would always give safe results for this type of configuration. This means that for a sparing level the predicted probability level would always be less than the simulated. As the time periods increased the predicted values will correspond more closely to the simulated values. This can be seen from Table 5.14.

The fifth area of interest was where all of the process density functions were normal. Case H in Table 5.15 shows the normals when the coefficient of variation is greater than one. Assuming a α level of .05 this case has seven time periods where there is enough information to reject the hypothesis that the sparing configuration is normal.

It is known that there was a possibility of obtaining a negative value of time in this case. It was possible that this type of situation could cause more spares to be used than were necessary. This was proven by Case I in Tables 5.17 and 5.18 which showed that for all time periods

that the simulation sparing levels were reduced. This reduction did not bring the simulation and prediction technique into closer agreement; in fact, it did exactly the opposite. The reasoning behind this is quite obvious. If a process was allowed to have a negative time period then that system would require more spares than if the time period was made zero. By being a negative time period it would take away from the total time the system had been in operation.

The α levels for Case I in Table 5.17 show that none of the time periods would provide sufficient information to reject the hypothesis if a α level of .05 was used. From this it would be possible to conclude that even though the process density function truncated normal the sparing configuration could not be rejected as not being a normal density function.

This case was based upon the coefficient of variation being greater than one for each process. Thus it can be seen that the prediction technique will give safe values of sparing levels. This safe level will end up providing more spares than are necessary for a sparing level.

The other case was where normal processes were used but the coefficient of variation was less than one. These results were Case J and Case K. Case J in Table 5.19 had three time periods where there was enough information to reject the hypothesis of normal sparing configuration. This

rejection of normality can be traced to the fact that the time periods were allowed to go negative.

Considering the fact that some of the sparing configurations were not normal, the individual time periods show very good correlation between the simulated and predicted probability levels. There was a better correlation than in Case H because there were less negative time periods entered into the simulation.

Case K in Table 5.21 was run so that no negative time periods could enter into the simulation. By comparing the means for the corresponding time period, it is found that those for Case K tend to be smaller than those for Case J. This difference is not as significant as that involved in Case H and Case I. There was no corresponding pattern developing between the standard deviations. The probability levels do not correspond as well as in Case K as in Case J.

The prediction technique can give excellent results for processes that have a normal probability density function. These results are improved by making the coefficient of variation less than one for each process. This would make the probability of obtaining negative time periods smaller and thus give better results.

The sixth area of interest was concerned with the case where the time periods were required to operate at different lengths. These results were in Case L, Table 5.23. Assuming a α level of .05 there would not be enough information to

reject the hypothesis of normality for any of the sparing configuration.

The ratios of the mean and standard deviation show a small amount of variation. The ratios tend toward a value of unity.

From the results it can be concluded that for probability levels less than 80 per cent the predicted value will be larger than the simulated value. For a probability level the predicted spare level will be correct or at most it will be short one spare to give the actual probability level. This tendency holds for low multiples of the mean of the sparing cycle. The predicted value will consistently give safe results above eight multiples of the mean of the sparing cycle. In other words, using the prediction technique guarantees that there will be enough spares and the actual probability will be higher than the desired.

The results for this case were drawn from systems composed of the same process parameters as Case D. The same general tendency was seen to develop in both cases. Using this as a basis it would be plausible to expect the other cases to develop in the same manner if unequal time periods were used.

Summary

The prediction technique that was used throughout this study showed promising results. In all of the cases above approximately 80 per cent, the prediction technique was

pessimistic. In a sense, the prediction technique would require enough spares and generally more than would be desired.

The prediction technique gives better results as the number of processes per system is increased. If the time that the system is desired to be used is increased, the results are improved. The coefficient of variation and the skewness of the process density functions affect the results. If the coefficient of variation is one or less the results of the prediction technique will correspond with better accuracy.

For the time that would be put into early predictions of spares this technique would be excellent. It is short, and the computations are easy to perform. The most difficult part of using the prediction technique would be the calculations of the third moment about the mean.

The value of the prediction technique depends upon the factors that are being used. As has been stated previously better results are obtained with different combinations of processes and with certain probability density functions. All of these factors must be taken into account when the prediction technique is used.

Through the author's experiences encountered in the development of this paper, the prediction technique would be better for preliminary work than would simulations. This experience is based upon time and cost. Time and cost are

directly related and they increase rapidly with the complexity of the simulation. In the early work on a project the simulation cost would be entirely prohibitive if the system parameter was changed quite often. The prediction technique gives results that show good comparison with the simulation so it should be the first choice of the designer if he is working under a tight budget.

Major areas were developed in this paper and the relationship between the sparing technique and the simulations have been observed. Further areas of study should be performed upon the sparing technique. The areas of interest that were presented should be studied in greater depth.

The coefficient of variation should be set at many different values and the effect upon the sparing level could be observed. The process probability density function of time to failure could then be changed to probability density functions other than those that were used in this presentation. This procedure would provide further conclusions than those that were presented in this paper.

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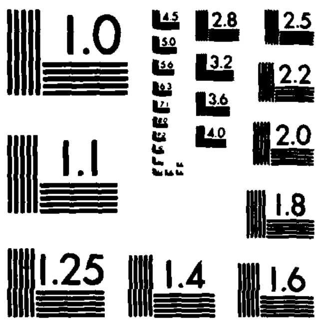

MICROCOPY RESOLUTION TEST CHART
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APPENDIXES

APPENDIX I

PREDICTION TECHNIQUE COMPUTER PROGRAM

The prediction technique computer program was written utilizing the equations of Chapter II and the logic of Chapter IV. The program was set up to handle any combination of systems and the corresponding processes. This is illustrated in Figure I.1 and the sample program.

The probability density function of time to failure for each process would have to be decided. This affects the type of parameters that have to be initialized. The initial values of NOSYS, JPROC, IPROC, MEAN(I), VAR(I), PKNOW, T(I), and B(I), if required, would have to be decided. The values used were those found in the odd numbered tables in Chapter V. Thus these values would only have to be keypunched and placed in the program deck in the manner as that of the sample program.

The other major factor for the calculation is that of the third moment about the mean. This value is totally dependent upon the probability density function for each of the processes. The normal probability density function has a MC3 value of zero. The exponential has a MC3 value that can be calculated by:

```
      MC3 = 0.0
      DO 777  I=1, JPROC
  777 MC3 = MC3 + 2*MEAN(I)**3.
```

The Weibull probability density function has a MC3 value calculated by the following technique:

```
      MC3 = 0.0
      DO 777  I=1,JPROC
      XX = 1.0 + 1.0/B(I)
      CALL GAMMA (XX, GX, IE)
      A(I) = (MEAN(I)/GX) ** B(I)
      XY = 1.0 + 2.0/B(I)
      CALL GAMMA (XY, GY, IE)
      VAR(I) = (GY - GX**2) *A(I)**(2.0/B(I))
      XZ = 1.0 + 3.0/B(I)
      CALL GAMMA (XZ, GZ, IE)
      MC3 = MC3 + (GZ - 3*GY*GX + 2*GX**3) *A(I)**(3/B(I))
  777 CONTINUE
```

These techniques can then be inserted into the program deck with the initial values to calculate the MC3 values. The remaining part of the program deck requires no modification.

The significant variables for the program are listed below.

<u>VARIABLES</u>

NOSYS	----------------------	number of systems
JPROC	----------------------	number of processes per system
IPROC	----------------------	process before spare re quired

MEAN(I) I=1,JPROC -----------	mean of each process
VAR(I) I=1, JPROC -----------	variance of each process
MC3(I) I=1,JPROC ------------	third moment about mean of each process
PKNOW ------------------------	probability of sufficient spares
T(I) I=1,NOSYS ---------------	time period required of each system
TIME -------------------------	Equation 2.1
UC ---------------------------	Equation 2.2
VARC -------------------------	Equation 2.3
K1 ---------------------------	Equation 2.4
K2 ---------------------------	Equation 2.5
ZALPA ------------------------	standardized normal value using PKNOW
UONE -------------------------	Equation 2.6
SONE -------------------------	Equation 2.7
SPARE ------------------------	Equation 2.8
NSPARE -----------------------	SPARE rounded upward to nearest integer value
UP ---------------------------	Equation 2.9
VARP -------------------------	Equation 2.10
UPRIM ------------------------	Equation 2.11
ZPRIM ------------------------	Equation 2.12
PTEST ------------------------	normal probability calculated using ZPRIM. Corresponding to NSPARE used in its calculation.
PROBI ------------------------	scientific subroutine supplied by IBM

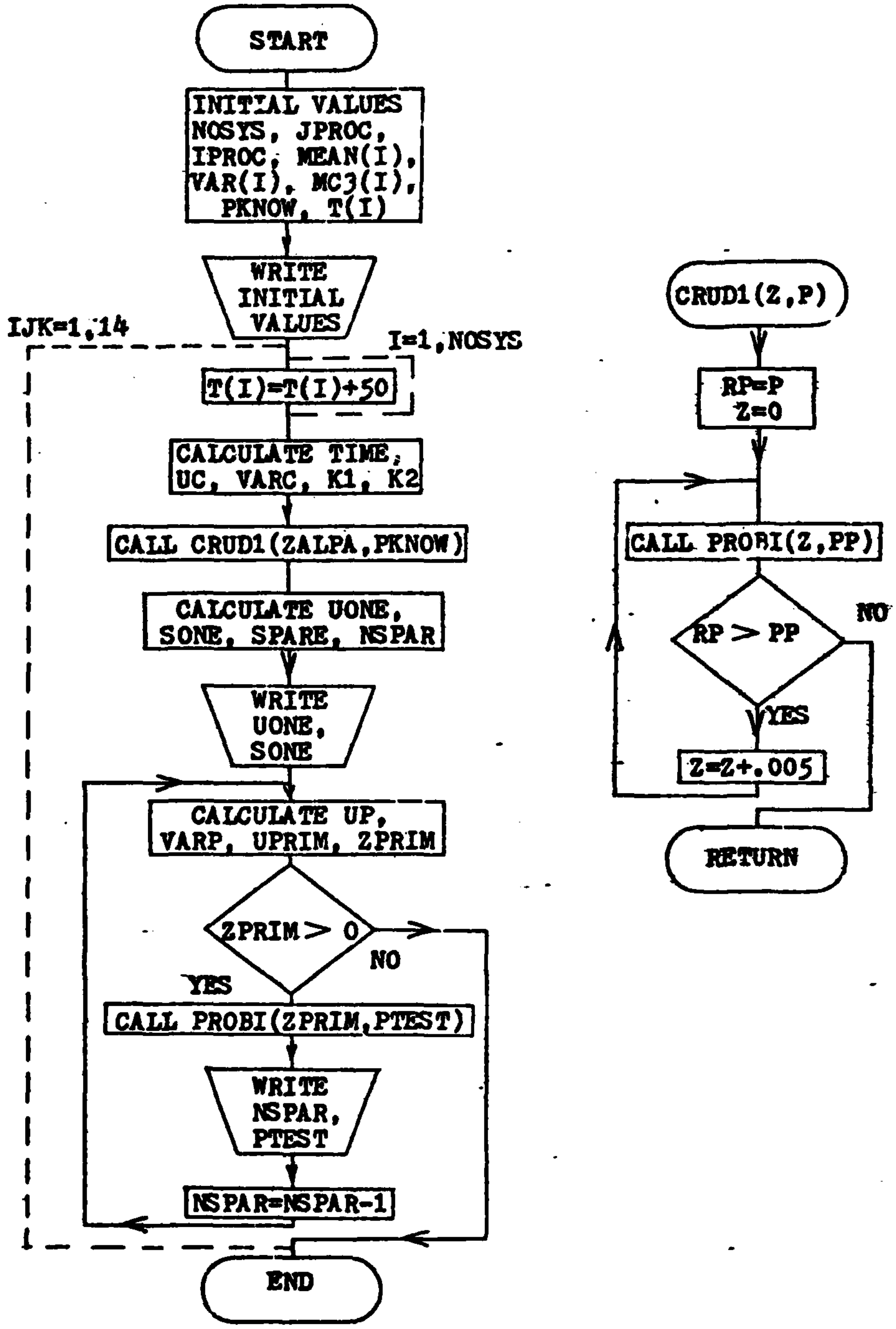

FIGURE I.1 FLOW CHART PREDICTION TECHNIQUE

```
      REAL T(100), MEAN(100), VAR(10 ), K1, K2, KC3
C
C     NOSYS                       NUMBER OF SYSTEMS.
C     T(I) I=1,NOSYS              TIME THAT EACH SYSTEM IS REQUIRED.
C     PRNOW                       PROBABILITY THAT IS DESIRED.
C     JPROC                       NUMBER OF PROCESSES PER SYSTEM.
C     IPROC                       PROCESS BEFORE SPARE REQUIRED.
C     MEAN(I) I=1,JPROC           MEAN OF EACH PROCESS.
C     VAR(I)  I=1,JPROC           VARIANCE OF EACH PROCESS.
C     TSYS                        TOTAL TIME.
C
C     ?   NORMAL   CASE    SO/I   G.T.   I
C
      NOSYS=?
      JPROC=?
      IPROC=1
      MEAN(1)=35.0
      MEAN(2)=7.0
      MEAN(3)=6.0
      VAR(1)=2242.?
      VAR(2)=8?.6813
      VAR(3)=117.1347
      KC3=?.0
      PRNOW=?.??90
      T(1)=?.0
      T(2)=?.0
      T(3)=?.0
C
C     WRITE INPUT DATA.
C
      WRITE(6,603) NOSYS,JPROC,IPROC,PRNOW
  603 FORMAT('1',//,15X,'INPUT DATA.',//,15X,'NUMBER OF SYSTEMS IS',I5,'
     1 .',/,15X,'NUMBER OF PROCESSES PER SYSTEM IS',I5,' .',/,15X,'POSIT
     2ION OF LAST PROCESS BEFORE SPARE IS',I5,' .',/,15X,'THE DESIRED AV
     3AILABILITY OF THE SYSTEMS IS  ',F6.2,' .',/ )
      DO 606 I=1,JPROC
  606 WRITE(6,605) I,MEAN(I),I,VAR(I)
  605 FORMAT(15X,'MEAN(',I2,') =',F10.2,15X,'VARIANCE(',I2,') =',F10.2)
C
C     INCREMENT TIMES THAT SYSTEMS ARE DESIRED TO OPERATE.  THEN
C         WRITE TIMES.
C
      DO 101 IJK=1,1?
      T(1)=T(1)+5?.0
      T(2)=T(2)+5?.
      T(3)=T(3)+5?.
      WRITE(6,609)
  609 FORMAT(///,15X,'OUTPUT DATA.',/)
```

```
      DO 608 I=1,NOSYS
  608 WRITE(6,607) I,T(I)
  607 FORMAT(15X ,'TIME SYSTEM(',I2,') =',F10.2,'.')
C
C     FIND TIME OF SYST[illegible] , EQUATION 2.1    .
C
      TSYS=0.0
      DO 10[illegible] I=1,NOSYS
      TSYS=TSYS+T(I)
  1[illegible] CONTINUE
      [illegible]
      [illegible]
      I[illegible]
  1[illegible] CONTINUE
      II=[illegible]
      DO 1[illegible] I=II,J[illegible]
C
C     EQUATI[illegible] 2.2 AND EQUAT[illegible] 2.3    .
C
      [illegible]
      [illegible]VA[illegible]=V[illegible]+VAR(I)
  1[illegible] CONTINUE
  1[illegible] CONTINUE
      [illegible]=TSYS+[illegible]SYS[illegible]
C
C     FI[illegible] PROCESS [illegible].
C
      VA[illegible]=[illegible]
      [illegible]
      DO 1[illegible] I=1,J[illegible]
      [illegible]
      [illegible]
  1[illegible] CONTINUE
C
C     CALCULATE K1 AND [illegible]S, EQUATI[illegible] 2.4 AND EQUATION 2.5    .
C
      K1=(U[illegible]-VARC)/([illegible]).
      K2=1./1[illegible]
C
C     FIND ZALPA USING [illegible].
C
      PK[illegible]=PKN[illegible]
      CALL C[illegible](ZALPA,PK[illegible])
      PK[illegible]=PK[illegible]
C
C     FIND FIRST ESTIMAT[illegible] OF [illegible], EQUATIONS 2.6, 2.7, AND 2.8    .
C
      [illegible]/UC-[illegible]SYS[illegible]
```

```
      SMPC=(((ICAVSPZ/J((...(SVS**2)**.5
      SPARE=...(C*ZALP....
      NSP=...SPARE+1.
C
C     WRITE THE FIRST ESTIMATE OF THE MEAN AND STANDARD DEVIATION.
C
      WRITE(6,602) ...
  602 FORMAT(/,15X,'MEAN VALUE SPARE',F1?.4,'.',/,15X,'STANDARD DEVIATIO
     1N SPARE',F1?.4,//,15X,'SPARE',5X,'PROBABILITY',/)
C
C       AT THIS POINT I, THE PROGRAM EQUATIONS 2.?, 2.10, 2.11, AND 2.12
C            ARE USED TO DETERMIN THE SPARING LEVEL AND CORRESPONDING
C            PROBABILITY. IF THE DESIRED PROBABILITY IS NOT FOUND THEN
C            THESE EQUATIONS ARE THEN REPEATED.
C
  11? CONTINUE
      ...
      ...SVS=VA...
      ...ISVS=1...
C
C     ... Z VALUE ... ESTIMATE.
C
      Z...
      IF(Z...) 13?,12?,12?
  12? CONTINUE
C
C     USING ZPEIS FIND STANDARD NORMAL PROBABILITY.
C
      CALL ...(Z...,...)
      ...
      WRITE(6,61?) ...
  61? FORMAT(...,I5,...)
      ...
      GO TO 11?
  13? CONTINUE
  1??? CONTINUE
      RETURN
      END
```

```
      SUBROUTINE [illegible](Z,P)
C
C     SUBROUTINE TAKES [illegible] PROBABILITY [illegible] NORMAL Z VALUE.
C
      P0=P
      Z=0.0
      IF(P-.5) 1 ,11,1[illegible]
   10 CONTINUE
      P0=1.-P
   11 CONTINUE
      CALL [illegible](Z,PP)
      PP=.5+PP/2.
      IF(PP-P0) [illegible],20,[illegible]
   21 CONTINUE
      Z=Z+. [illegible]
      GO TO 11
   20 CONTINUE
      IF(P-.5) 30,31,31
   30 CONTINUE
      Z=-Z
      CALL [illegible](Z,PP)
      P=.5-PP/2.
      GO TO 1[illegible]
   31 P=P0
  10[illegible] CONTINUE
      RETURN
      END
```

```
      [illegible]
C
C     [illegible] CALCULATE STANDARD NORMAL PROBABILITY.
C
      [illegible]
   11 [illegible]
      [illegible]-X*(0.26628
     1[illegible]
      GO TO 1020
   12 IF(X-[illegible]) 13,[illegible],14
   13 [illegible]
      [illegible]=1.
      [illegible]
      [illegible]
      [illegible]
   [illegible] [illegible]
      [illegible]
      [illegible]
      IF(ABS([illegible])-[illegible]) [illegible]
   [illegible] [illegible]
      [illegible]
      GO TO [illegible]
   [illegible] [illegible] .7071[illegible]
      GO TO 1020
   14 [illegible]
      [illegible]/X*(1.0-[illegible](1.
     1-[illegible]35.)))))
 1020 RETURN
      END
```

APPENDIX II

Simulation Computer Program

The simulation computer program was written utilizing the logic of Chapter IV. The program was written so that the parameters for the systems under consideration would only have to be placed at the beginning of the program in order to change the simulation.

The flow chart of the sample program is presented in Figure II.1. This flow chart shows the first step is the reading of the random array IX. These values are formated and read into the program as in Figure II.2. As in the computer program for the prediction technique the initial systems and processes must first be decided. The probability density function for each process must also be defined.

The initial parameters are those that were presented in Chapter V. These parameters are NS, JP, IP, M(I), V(I), and T(I). These values can be keypunched and put in the program deck as is illustrated in the sample program given in this appendix.

The probability density function of the processes must now be accounted for. If the processes are normal or exponential then enough parameters have been specified. If the processes are Weibull then other values must be established. As an example of this consider the case of three Weibulls where the coefficient of variation is greater than one.

```
      NS=3
      JP=3
      IP=1
      M(1)=35.0
      M(2)=7.0
      M(3)=8.0
      B(1)=.5
      B(2)=.75
      B(3)=.75
      DO  777 I=1,3
      XX=1.0 + 1.0/B(I)
      CALL GAMMA(XX,GX,IE)
      A(I)=(M(I)/GX)**B(I)
      XY=1.0 + 2.0/B(I)
      CALL GAMMA(XY,GY,IE)
  777 V(I)=(GY - GX**2)*A(I)**(2.0/B(I))
```

This will give the desired initial values of A(I) and V(I) for the simulation. To simulate for the values given in this paper, it would only be necessary to keypunch the values presented in the tables in Chapter V using the correct variable name. These values would be NS, JP, IP, M(I), V(I), T(I), B(I), and A(I). This would be done even if the process had different probability density functions. It would only be necessary to put the correct parameters in the program deck.

The second change in the program is also dependent upon the process probability density functions. This change is made in the program deck following the "105 CONTINUE" statement. This can be seen in the sample program. The sample

program illustrates the card deck if all of the processes are normal. Also, this program does not allow negative time which is shown by the statement following CALL GAUSS. To correct this program in order to handle three normal processes without truncation it would only be necessary to remove the "IF" statement and statements 3000 and 3001.

The exponential case is created by removing the CALL GAUSS statement and the "IF", if it is present. The exponential uses the sequence:

```
      DO 100  I=1,Jp
      CALL RANDU (IX,IY,FG)
      IX=IY
      TI=-M(I)*ALOG(1.0-FG)
      KT=KT + 1
```

Those cards used with the exponential parameters placed in the beginning of the deck will give the desired simulation.

To run a simulation using mixed process probability density functions another technique was used. The case where the three processes were in the order Weibull, normal, and Weibull will now be presented.

```
      DO 100  I=1,JP
      CALL RANDU(IX,IV,FG)
      IX=IY
      GO TO (10,20,30),I
   10 TI=(-A(I)*ALOG(1.0-FG))**(1.0/B(I))
      GO TO 101
   20 CALL GAUSS (IX,VV(I),M(I),TI)
      GO TO 101
```

```
 30 TI=(-A(I)*ALOG(1.0-FC))**(1.0/B(I))
101 CONTINUE
```

As can be seen from the above example once the process probability density function is known the equation of the probability density function of time to failure can be rearranged so that given a probability of failure the corresponding time to failure can be found.

The significant variables for the program are listed below:

VARIABLES

IX	initial seed values for scientific subroutines
IT(I) I=1,50	array of random IX values
NS	number of systems
JP	number of processes per sparing cycle
IP	process before a spare is added to system
M(I) I=1,JP	mean array for processes
V(I) I=1,JP	variance array for processes
T(I) I=1,NS	time period array for systems
IS	spares array for simulation
IJ	array of seed values that start simulations for one time period
TC	time check which is being incremented by time of each process TI

TI	time increment of each process
FREQ	frequency array of spares showing how many lines a spare level was used
U	running mean of number of spares array
SD	running standard deviation of spares array
NT	total number of simulations run
CHECK	variation between two consecutive means of spares array
CRUD6	subroutine to take spares array and create frequency array
IA	number of frequency intervals plus two
PC	percentage value for each frequency interval
RI	lower sparing level cut off point
R	theoretical frequency
PT	per cent total
F	sample frequency
TS	x^2 test value
ID	degrees of freedom x^2 test value

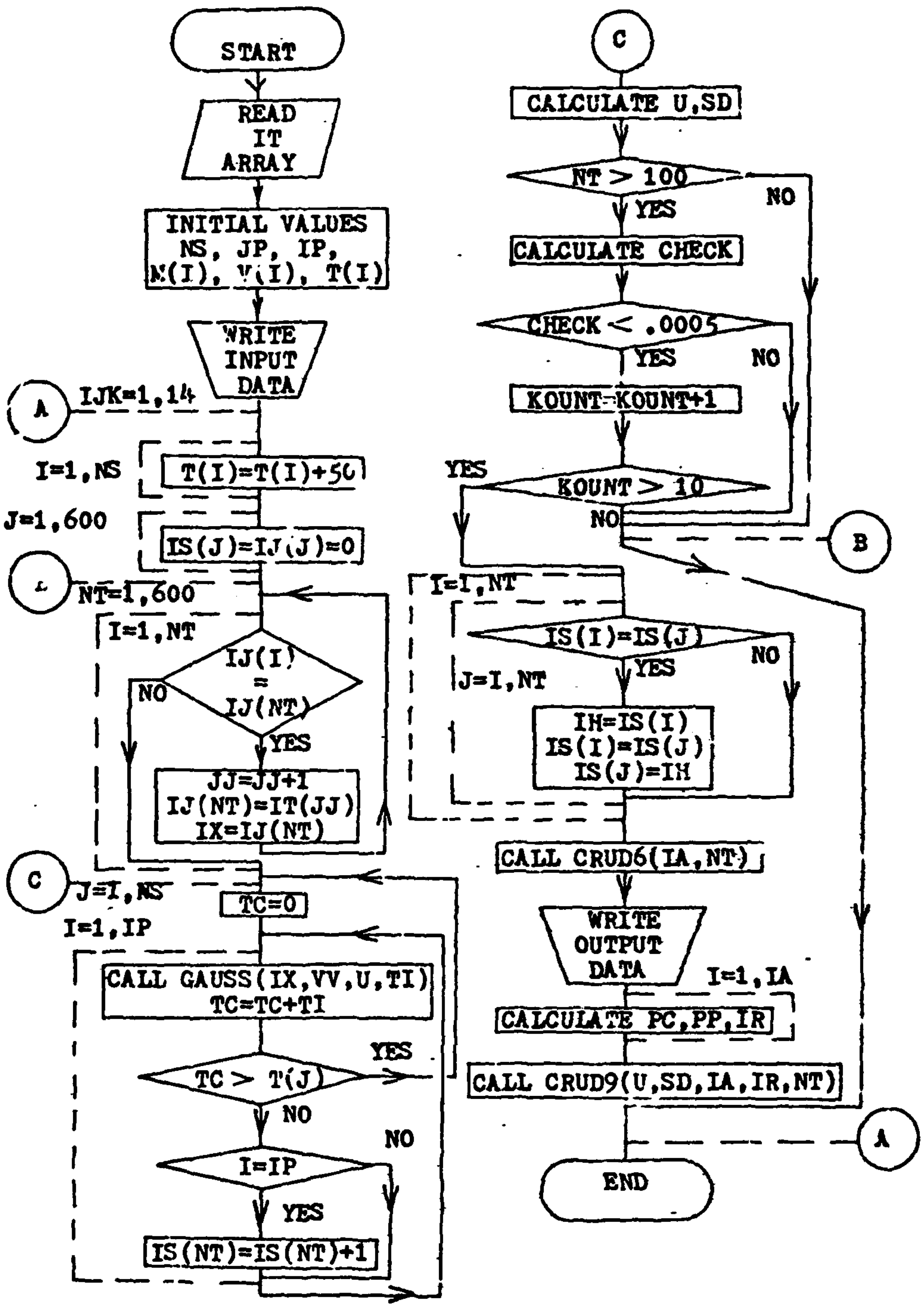

FIGURE II.1 FLOW CHART SIMULATION

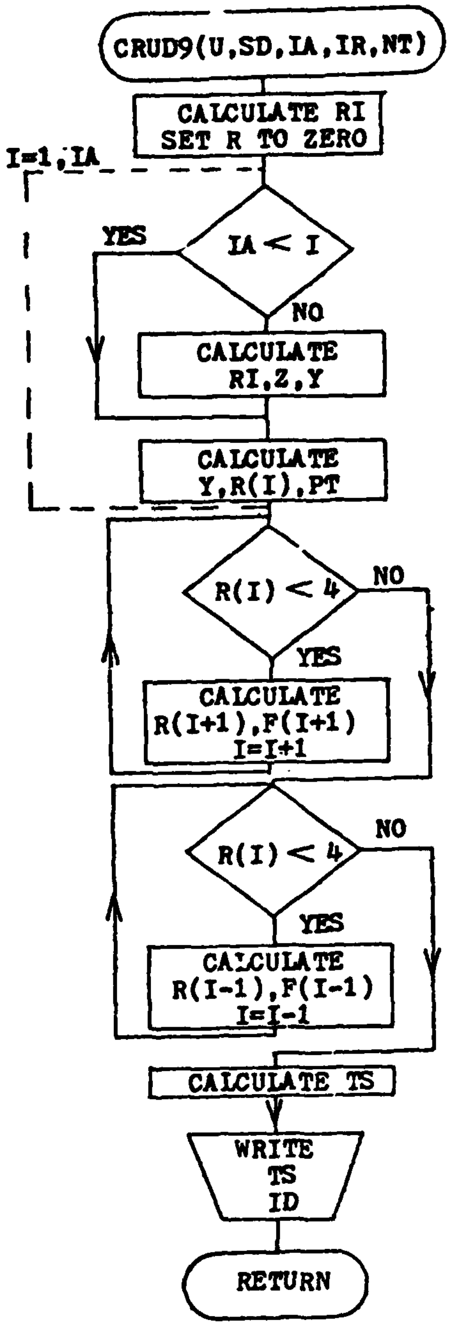

FIGURE II.1 (continued) FLOW CHART SIMULATION

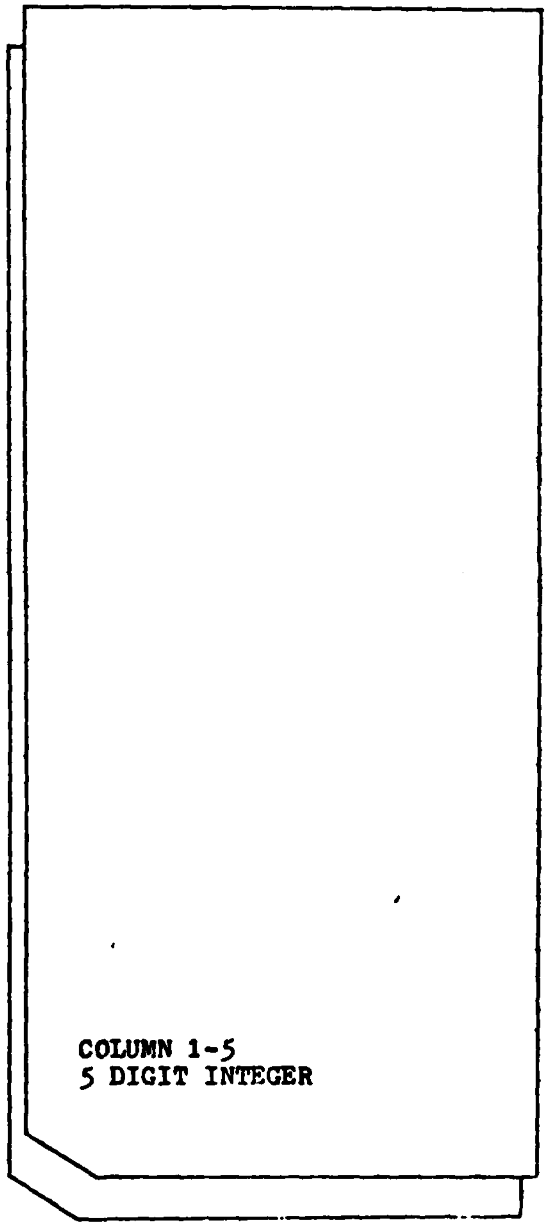

FIGURE II.2 INPUT DATA SIMULATION

```
      REAL M(3),V(3),T( 3),VV(3)
      DIMENSION IJ(600),IT(50)
      COMMON      IS(600),FREQ(50)
C
C     NT  NUMBER OF TIMES SIMULATED SPARES.
C     KT  NUMBER OF ITERATIONS DURING A SIMULATION.
C     RT  TOTAL NUMBER OF RANDOM VARIABLES CALLED.
C     NS  NUMBER OF SYSTEMS.
C     IS  SPARES ARRAY FROM SIMULATION.
C     M   MEAN ARRAY.
C     V   VARIANCE ARRAY.
C     T   TIME ARRAY.
C     JP  NUMBER OF PROCESSES PER SPARING CYCLE.
C     IP  LAST PROCESS BEFORE A SPARE IS ADDED TO THE SYSTEM.
C     IC  CHECK ON IS VALUE.
C     TC  TIME CHECK.
C     TI  TIME INCREMENT FORM ONE SIMULATION.
C     PS  PREVIOUS SIMULATION MEAN.
C     JJ  COUNTER TO SEE HOW MANY IX VALUES HAVE BEEN READ.
C     IT  ARRAY OF RANDOM IX VALUES.
C     U   MEAN OF SPARES.
C     SD  STANDARD DEVIATION OF SAMPLE.
C     DS  UNBIASED ESTIMATE OF SD .
C
C     READ IN INITIAL SEED VALUE.
C
      DO 3 I=1,50
      READ(5,121) IT(I)
  121 FORMAT(I5)
    3 CONTINUE
      IX=IT(1)
      JJ=1
C
C     3   NORMAL   CASE   S.D./U   G.T.   1
C
      NS=3
      JP=3
      IP=1
      M(1)=35.0
      M(2)=7.0
      M(3)=4.0
      V(1)=2242.0222
      V(2)=49.6713
      V(3)=117.1347
      VV(1)=V(1)**.5
      VV(2)=V(2)**.5
      VV(3)=V(3)**.5
      T(1)=0.0
```

```
      T(2)=0.0
      T(3)=0.0
C
C     WRITE INPUT DATA.
C
      WRITE(6,556) NS,JP,IP
  556 FORMAT('1',///,25X,'INPUT DATA.',//,25X,'NUMBER OF SYSTEM',I4,/,25
     1X,'NUMBER OF PROCESSES',I4,/,25X,'PROCESS BEFORE SPARE',I4)
      DO 11 I=1,JP
      WRITE(6,557) I,M(I),I,V(I)
  557 FORMAT(25X,'MEAN(',I3,') = ',F9.2,5X, 'VAR(',I3,') = ',F9.2)
   11 CONTINUE
C
C     INCREMENT TIMES FOR SYSTEMS.
C
      DO 1011 IJK=1,I4
      T(1)=T(1)+50.0
      T(2)=T(2)+50.0
      T(3)=T(3)+50.0
      PT=0.0
      TC=0.0
      PP=0.5
      KOUNT=0
      SUM=0.0
      SSUM=0.0
      DO 551 J=1,600
      IS(J)=0
  551 IJ(J)=0
C
C     START SIMULATION.
C
      DO 112 NT=1,600
C
C     CHECK STARTING VALUE OF IX FOR POSSIBLE RECYCLING.
C
      IJ(NT)=IX
      IC=NT-1
      IF(NT-1) 6,6,2
    2 DO 4 I=1,IC
      IF(IJ(I)-IJ(NT)) 4,4,4
    4 CONTINUE
      JJ=JJ+1
      IJ(NT)=IT(JJ)
      IX=IJ(NT)
      GO TO 2
    6 CONTINUE
      IS(NT)=0
      KT=0
```

```
C
C     CHECK EACH SYSTEM TO SEE HOW MANY SPARES IT NEEDS.
C
      DO 103 J=1,NS
      TC=0.0
  105 CONTINUE
C
C     FOR ONE SYSTEM FIND A RANDOM TIME FOR EACH PROCESS.
C
      DO 100 I=1,JP
      CALL GAUSS(IX,VV(I),M(I),TI)
      IF (TI) 3000,3001,3001
 3000 TI=0.0
      KT=KT+1
 3001 CONTINUE
      TC=TC+TI
      IF(TC-T(J)) 102,103,103
  102 CONTINUE
      IF(I-JP) 100,104,104
  104 CONTINUE
      IS(NT)=IS(NT)+1
  100 CONTINUE
      GO TO 105
  103 CONTINUE
C
C     CALCULATE A RUNNING MEAN AND STANDARD DEVIATION OF SPARES
C        CONFIGURATION.
C
      RT=RT+KT
      SUM=SUM+IS(NT)
      SSUM=SSUM+(FLOAT(IS(NT)))**2
      SD=((SSUM-(SUM**2)/NT)/NT)**0.5
      CHECK=SUM/NT
      U=CHECK
      DT=SUM
C
C     CHECK TO SEE IF HAVE RUN 100 TIMES AND IF SO CHECK TO SEE IF
C        MEAN IS DEVIATING, AND IF NOT STOP SIMULATING TIMES.
C
      IF(NT-100) 112,111,111
  111 CONTINUE
      CHECK=1.0-CHECK*(NT-1)/PR
      PR=SUM
      IF(ABS(CHECK)-0.0005) 115,115,112
  115 CONTINUE
      KOUNT=KOUNT+1
      IF(KOUNT-10) 112,120,120
  112 CONTINUE
```

```
      GO TO 1310
  120 CONTINUE
C
C     SORT SPARES IN ASCENDING ORDER.
C
      DO 501 I=1,NT
      DO 501 J=I,NT
      IF(IS(I)-IS(J)) 501,501,502
  502 CONTINUE
      IH=IS(I)
      IS(I)=IS(J)
      IS(J)=IH
  501 CONTINUE
C
C     FIND THE RANGE.
C
      RANG=IS(NT)-IS(1)
      IA=RANG+2
C
C     DEVELOPE FREQUENCY ARRAY.
C
      CALL CRUNA(IA,NT)
      RLEN=RANG/(IA-2)
C
C     WRITE OUTPUT DATA.
C
      WRITE(6,650)
  650 FORMAT(///,25X,'OUTPUT DATA.',/)
      DO 554 I=1,NS
  554 WRITE(6,550) I,T(I)
  550 FORMAT(25X,'SYSTEM TIME(',I3,') = ',F10.0)
      WRITE(6,651) NT,CT,IS(1),IS(NT)
  651 FORMAT(/,25X,'NUMBER OF SIMULATIONS',I5,/,25X,'NUMBER OF TIMES CAL
     1LED RANDOM VARIABLES',F9.1,/,25X,'LEAST USED',I5,5X,'MOST USED',I5
     2)
      DS=SD*(FLOAT(NT)/FLOAT(NT-1))**.5
      WRITE(6,899) U,RANG,DS,SD,ST,RLEN
  899 FORMAT(/25X'MEASURES OF SPARING DISTRIBUTION.',// ,25X,'MEAN',T6
     10,F9.4,/ ,25X,'RANGE',T60,F8.3,/ 25X,'STANDARD DEVIATION (UNBIASED
     2)',T60,F9.4,/ ,25X,'STANDARD DEVIATION (SAMPLE)',T60,F9.4,/ ,25X,'
     3TOTAL',T60,F9.2,    5X,'LENGTH OF INTERVALS',    F8.4,/)
      IP=IS(1)-2
C
C     FIND PERCENTAGES FOR EACH SPARE LEVEL AND WRITE FREQUENCYU ARRAY.
C
      PP=0.0
      DO 216 I=1,IA
      PC=FREQ(I)*100./FLOAT(NT)
```

```
      PP=PP+PC
      IN=IP+1
      WRITE(6,917) I,SPCO(I),I,PC,PP,I,IN
  917 FORMAT(' ',25X,'FREQ(',I2,') =',F6.2,5X,'PCT(',I2,') =',F6.2,5X,F6
     1.2,5X,'INTERVAL(',I2,') ',I4,' SPARES')
  916 CONTINUE
      IP=IS(I)
C
C     PERFORM CHI-SQUARED GOODNESS OF FIT TEST ON SPARE CONFIGURATION.
C
      CALL CHUCHI(N,SP,IA,IW,NT)
      WRITE(6,722)
  722 FORMAT('1')
 1010 CONTINUE
 1011 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE CONDA(INN,NP)
      COMMON II(500),FREQ(50)
C
C     CLEAR OUTPUT AREAS.
C
      DO 65 I=1,INN
   65 FREQ(I)=0.0
C
C     CALCULATE INTERVAL SIZE.
C
      SINT=ABS((II(NP)-II(1))            )/(INN-2.0))
C
C     DEVELOP FREQUENCIES.
C
      DO 75 J=1,NP
      TEMP=II(1)-SINT
      INTV=INN-1
      DO 60 I=1,INTV
      TEMP=TEMP+SINT
      IF(II(J)-TEMP) 70,60,60
   60 CONTINUE
      IF(II(J)-TEMP) 70,66,66
   66 FREQ(INN)=FREQ(INN)+1.0
      GO TO 75
   70 FREQ(I)=FREQ(I)+1.0
   75 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE CHIMOD(X,SD,IA,IM,NT)
      DIMENSION X(50)
      COMMON ...
C
C     SUBROUTINE PERFORMS A CHI-SQUARED GOODNESS OF FIT TEST.
C
C     F       SAMPLE FREQUENCY ARRAY.
C     IU      UPPER FREQUENCY POINT AND TO.
C     IL      LOWER FREQUENCY POINT AND TO.
C     Z       NORMAL VALUE.
C     PI      CUTT OFF POINT.
C     PT      PERCENT TOTAL.
C     R       THEORETICAL FREQUENCY.
C
      PI=FLOAT(I?)-1.5
      DO 63 I=1,??
   63 F(I)=0.0
      PT=0.0
C     FIND FREQUENCY FOR EACH SPACING SET.
      DO 50 I=1,IA
      IF(IA-I) 45,46,46
   45 CONTINUE
      Y=100.0
      GO TO 22
   46 CONTINUE
      PI=PI+1.0
      Z=(PI-U)/SD
      IF(Z) 20,21,21
   20 CONTINUE
      Z=-Z
      CALL PROB(Z,Y)
      Z=-Z
      Y=50.0-50.0*Y
      GO TO 22
   21 CONTINUE
      CALL PROB(Z,Y)
      Y=50.0+50.0*Y
   22 CONTINUE
      Y=Y-PT
      R(I)=NT*Y/100.0
      PT=PT+Y
   50 CONTINUE
C     FIND IF THE VALUES OF THE FIRST AND LAST FREQUENCY ELEMENTS ARE
C     GREATER THAN FOUR.
      I=1
   27 CONTINUE
      IF(R(I)-4) 25,26,26
   25 CONTINUE
```

```
      W(I+1)=W(I+1)+W(I)
      F(I+1)=F(I+1)+F(I)
      I=I+1
      GO TO 27
   24 CONTINUE
      IL=I
      I=I*
   33 CONTINUE
      IF(W(I)-4) 31,32,42
   31 CONTINUE
      F(I-1)=W(I-1)+W(I)
      F(I-1)=F(I-1)+F(I)
      I=I-1
      GO TO 33
   32 CONTINUE
      IU=I
C     CALCULATE THE CHI-SQUARED VALUES.
      S=0.0
      TS=0.0
      DO 60 I=IL,IU
      S=((F(I)-W(I))**2)/W(I)
      TS=TS+S
   60 CONTINUE
      ID=IU-IL-2
      WRITE(6,62) IL,IU,ID,TS
   62 FORMAT(/,25X,'REGION USED IN DISTRIBUTION WAS FROM ',I3,'  TO ',I3
     1,'.',/,25X,'DEGREES OF FREEDOM ARE ',I4,'  FOR A SUM OF ',F10.4)
C     REARRANGE THE FREQUENCY DISTRIBUTION.
      J=1
      DO 9 I=IL,IU
      F(J)=F(I)
      J=J+1
    9 CONTINUE
      I*=IU-IL+1
      RETURN
      END
```

```
      SUBROUTINE [illegible]
      IF(X-1.29) 11,11,12
   11 XSQ=X**2
      PROBS= 0.797885*X*(0.999998-XSQ*(0.166596-XSQ*(.24638
     1E-1-XSQ*0.21[illegible])))
      GO TO 1000
   12 IF(X-3.00) 13,14,14
   13 XSQ=X*X
      PROBS=1.0
      PTERM=1.0
      FACTO=1.0
      POINT=3.0
  970 PTERM=-PTERM*XSQ/(2.0*FACTO)
      TERM=PTERM/POINT
      PROBS=PROBS+TERM
      IF(ABS(TERM)-.[illegible]) [illegible]
   98 FACTO=FACTO+1.0
      POINT=POINT+2.0
      GO TO 970
   99 PROBS=.797885*X*PROBS
      GO TO 1000
   14 RECXS=1.0/(X*X)
      PROBS=1.0-.797885*EXP(-X*X/2.0)/X*(1.0-RECXS*(1.0
     1-RECXS*(3.0-RECXS*(15.0-RECXS*105.0))))
 1000 RETURN
      END
```

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LOGIC CHART
COMPUTATION OF FLSIP COSALS

COMPONENT CONFIGURATION RECORD ←ENTER WITH HULL NO.

1. List of installed components and quantity per hull
2. Vital/Non-Vital Military Essentiality Code (MEC) component to hull level

↓

PART CONFIGURATION RECORD — OBTAIN FOR EACH ITEM

1. Maintenance Code
2. Part to Component MEC
3. Minimum Replacement Unit (MRU)
4. Planned Maintenance Requirement (PMR)
5. Technical Override Requirement (TOR)
6. Part Population

ALLOWANCE CANDIDATES (SELECTED ON MAINTENANCE CODE)

DEMAND QUALIFIER PROGRAM

$$\text{COMPONENT POP} \times \text{PART POP PER COMP} \times \frac{\text{BEST REPLACEMENT FACTOR (Annual)}}{4} \gtrless 1 \text{ (90 DAYS)}$$

EQUAL TO OR GREATER THAN 1

(A) DEMAND QUALIFYING ITEM
Provide sufficient qty to protect to 90% for 90 days

LESS THAN 1

INSURANCE ITEM PROGRAM
Is component vital or non-vital

YES

Is part vital or non-vital to component

NO

Reject item unless PMR or TOR designated

YES

DEEP INSURANCE CRITERIA
Total Part POP/HULL x BRF (Annual) $\gtrless$ .25/ANNUM

NO

Reject item unless PMR or TOR designated

EQUAL TO OR GREATER THAN .25

(B) INSURANCE ITEM
Provide quantity equal to MRU, PMR or TOR whichever is greater

LESS THAN .25

Reject item unless PMR or TOR designated

COMPUTATION OF FLSIP COSAL

This logic chart illustrates how the various inputs being collected incident to the FLSIP tie together and are used to compute the final allowance quantity.

We first enter our ICP automated component configuration record with the hull number for which we want to compute our requirement. We abstract from this configuration record a list of all components installed, their on-board installed population, their service application and the military essentiality of each component to the ship's mission.

Next, we enter our ICP automated component to part record with our list of components, and extract the list of individual parts together with the various technical and maintenance decisions which relate to them.

Using the maintenance code, we select the potential list of on-board candidates. Only those items authorized to be replaced on-board ship are selected as potential candidates.

These candidates then go through the demand qualifier program. Taking the total installed part population on that hull (obtained by multiplying the component population per hull times the part population per component), multiplying this quantity by the Best Replacement Factor (BRF) divided by 4 (to obtain a 90 day replacement rate), we determine whether the resultant quantity is equal to, less than or greater than 1.

If equal to or greater than 1, our item is classified as a demand based item in accordance with the definitions prescribed by OPNAVINST 4441.12A. An allowed quantity (depth) is computed for each demand based item which provides a 90% protection level for a 90 day period as required by CNO. This quantity is computed using the Poisson Distribution Formula. If the computed quantity is less than either the minimum replacement unit (MRU), planned maintenance requirement (PMR) or other technical override requirement (TOR), should these be applicable, the highest quantity among these three elements is selected as the authorized allowance.

If less than 1, the item is designated as an insurance item. The military essentiality of the component to which the item applies is screened to determine if the component is vital or non-vital to the mission of the ship. If the component is non-vital, the insurance items are rejected unless there is a designated PMR or TOR. If affirmative, the higher of these two elements is selected as the authorized allowance. If an item has multiple component applications both vital and non-vital, its military essentiality is always considered to be vital.

After screening for military essentiality at the component to mission level, a second screening is performed to determine whether the item itself, is vital or non-vital to the component. Non-vital items for vital components are also rejected unless there is a designated PMR or TOR. If affirmative, the higher of these two elements is selected as the authorized allowance.

A third and final screening is performed on each vital/vital item to determine if its probability of usage aboard ship is so low that it, also, should be rejected from allowance lists. A deep insurance criteria has been established which defines a deep insurance item as one with an expected usage aboard ship of less than .25 per annum based on its shipboard population and BRF. Based on this criteria, deep insurance items are rejected unless there is a designated PMR or TOR. If affirmative, the higher of these two elements is selected as the authorized allowance. If the forecast ship usage is equal or greater than .25, the highest of the MRU, PMR, or TOR is selected as the authorized allowance. The summation of the demand based and insurance items remaining after the above screenings become the authorized on-board allowance of repair parts for a particular hull.

FLSIP ALLOWANCE QUANTITY TABLE
(BASED ON 90 DAY SUPPORT)

$\frac{\text{BRF X POP}}{4}$	ALLOW QTY	$\frac{\text{BRF X POP}}{4}$	ALLOW QTY
<.0625	0	24.7 - 25.5	32
.0625 - .999	*	25.6 - 26.4	33
1.0 - 1.1	2	26.5 - 27.3	34
1.2 - 1.7	3	27.4 - 28.1	35
1.8 - 2.4	4	28.2 - 29.0	36
2.5 - 3.1	5	29.1 - 29.9	37
3.2 - 3.8	6	30.0 - 30.8	38
3.9 - 4.6	7	30.9 - 31.7	39
4.7 - 5.4	8	31.8 - 32.6	40
5.5 - 6.2	9	32.7 - 33.5	41
6.3 - 7.0	10	33.6 - 34.4	42
7.1 - 7.8	11	34.5 - 35.3	43
7.9 - 8.6	12	35.4 - 36.2	44
8.7 - 9.4	13	36.3 - 37.1	45
9.5 - 9.9	14	37.2 - 38.0	46
10.0 - 10.7	15	38.1 - 39.0	47
10.8 - 11.6	16	39.1 - 39.9	48
11.7 - 12.4	17	40.0 - 40.8	49
12.5 - 13.3	18	40.9 - 41.7	50
13.4 - 14.1	19	45.0	54
14.2 - 15.0	20	50.0	60
15.1 - 15.8	21	55.0	65
15.9 - 16.7	22	60.0	70
16.8 - 17.6	23	65.0	76
17.7 - 18.4	24	70.0	81
18.5 - 19.3	25	75.0	87
19.4 - 20.2	26	80.0	92
20.3 - 21.1	27	85.0	97
21.2 - 21.9	28	90.0	103
22.0 - 22.8	29	95.0	108
22.9 - 23.7	30	100.0	113
23.8 - 24.6	31	> 100.0	**

*These items are insurance items and are allowed only if the part to component MEC and component to Ship MECs are both vital. If the MECs are vital, the item is allowed in a quantity of one minimum replacement unit.

** If the mean $\left(\frac{\text{BRF X POP}}{4}\right)$ is greater than 100.0, the allowance quantity can be computed as

$$\text{Allowance} = \text{Mean} + 1.28\sqrt{\text{Mean}}$$

Prepared by: Navy Fleet Material Support Office (Code 97)
Mechanicsburg, Pa. Autovan 277 - 3641/2509

Authority: NSSC ltr SUP 04312/159 of 25 July 73 to FMSO copy to SPCC, ESO.
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ENCLOSURE (2)

(d) Any items, other than those qualifying under paragraphs 4c(1)(b) and 4c(1)(c), to be included in the allowance lists must satisfy the criteria and rules of TORs as set forth by Chief of Naval Material.

(e) Items considered essential to the operation of the equipment which are excluded from IOLs by the criteria above may be supported as supply system insurance items in a minimum quantity to satisfy emergency requirements.

d. Materiel Availability (effectiveness) goals:

(1) For aviation ships and MAGs, the objective for overall AVCAL performance is to fill 75% of all demands and to provide overall availability of 85% for items stocked. Issues from rotatable pools will be included in effectiveness computations. For non-aviation ships without intermediate maintenance capability, the objective is to fill 65% of all demands and to provide overall availability of 85% for items stocked.

(2) For shore activities supporting aircraft the objective for overall AVCAL performance is to fill 65% of all demands and to provide overall availability of 85% for items stocked. Issues from rotatable pools will be included in effectiveness computations.

e. Identification of overrides. Items which are included in allowance lists which qualified on other than rules cited above will be coded and identified in IM files for periodic review of original decision.

f. Depth of Stocks

(1) Rotatable pool stock levels will be based upon frequency of repair and actual turn around time, which in the majority of cases should not exceed 3 days. In any event individual item levels will be constrained to a quantity representing a maximum of 20 days turn around time.

(2) Authorized stock levels for repairable items at operating sites will be 90 days for afloat units and MAGs, 30 days for CONUS activities and 60 days for overseas activities. Afloat and overseas computations will be based on combat flying hours. Replenishment will be on a one for one basis with no additional depth authorized for order and ship time. CHNAVMAT will publish procedures for changing allowances. When promulgated, allowances will be

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END

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